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A

RECORD OF THE PROGRESS

OF

MODERN ENGINEERING.

1864.

COMPRISING

CIVIL, MECHANICAL, MARINE, HYDRAULIC, RAILWAY, BRIDGE, AND OTHER ENGINEERING WORKS.

63624

WITH

ESSAYS AND REVIEWS.

EDITED BY

WILLIAM HUMBER

ASSOCIATE OF INSTITUTE OF CIVIL ENGINEERS, AND MEMBER OF INSTITUTE OF MECHAN. ENGINEERS.

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LONDON:
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1865.

LONDON
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NEW-STREET SQUARE

ILLUSTRATIONS.

NAME AND DESCRIPTION.	SITUATION.	PLATES.	NAME OF ENGINEER.
Birkenhead Docks, Low Water Basin	Birkenhead	1 to 15	Mr. G. F. Lyster, C.E.
Charing Cross Station Roof—Charing Cross Railway	Charing Cross	16 to 18	Mr. Hawkshaw, C.E.
Digswell Viaduct—Great Northern Railway	Welwyn	19	Mr. J. Cubitt, C.E.
Robbery Wood Viaduct—Great Northern Railway	Near Welwyn	20	Mr. J. Cubitt, C.E.
Iron Permanent Way	...	20*a*	——
Clydach Viaduct—Merthyr, Tredegar, and Abergavenny Railway	Clydach Valley	21	Mr. Gardner, C.E.
Ebbw Viaduct—Merthyr, Tredegar, and Abergavenny Railway	...	22	Mr. Gardner, C.E.
College Wood Viaduct—Cornwall Railway	Penryn	23	Mr. Brunel.
Dublin Winter Palace Roof	Dublin	24 to 26	Messrs. Ordish and Le Feuvre.
Bridge over the Thames—London, Chatham, and Dover Railway	Blackfriars	27 to 32	Mr. J. Cubitt, C.E.
Albert Harbour, Greenock	Greenock	33 to 36	Messrs. Bell and Miller.

NOTE TO THE BINDER.

The Plates to be bound at the end of the Volume. Biographical Sketch of the Life of Robert Stephenson, Esq., to precede Address.

experiencing the perils of shipwreck. It was on this journey that he met with Trevithick, whose splendid dreams of wealth in Spanish America had terminated in the stern reality of almost absolute want; and there is little doubt, that the discussions on the steam engine between these original geniuses of such different character, led in the mind of Stephenson to a closer consideration of the locomotive.

On his arrival in England in December 1827, he found the Stockton and Darlington Line in full operation, and the Liverpool and Manchester Railway fast approaching completion. The question as to the best means of traction for the new road was already under discussion, and as the time for opening the line drew near, the controversy amounted to acrimony. Mr. James Walker, (Past-President Inst. C.E.,) and Mr. J. U. Rastrick, (M. Inst. C.E.,) who were employed by the company to investigate the subject, reported at first against the adoption of the locomotive so strenuously advocated by Stephenson, and they recommended the use of stationary engines. The Directors, however, determined on giving the locomotive a fair trial, and offered a premium of £500 for that engine which should best fulfil the required conditions. The offer led to the memorable Rainhill contests, at which the "Rocket" built by Robert Stephenson, with a boiler on the multitubular principle, suggested by Mr. Henry Booth, and under the guidance of George Stephenson, obtained an easy victory over the other competitors. The success of the "Rocket" decided the question of locomotive traction. Not content, however, with what he had already achieved, he resolved on effecting further improvements, and the "Planet," which virtually gave the type to all succeeding locomotives, was the result of his renewed exertions. From the period of the construction of the "Rocket," he still for several years persevered in his "endeavours to improve," and such was the success of those efforts, that, as has been justly said by Mr. Nicholas Wood, "to Mr. Robert Stephenson almost, if not quite, universal assent will be accorded as having the merit of raising the locomotive engine from what it was in 1829 to what it is in 1860."*

Between the close of 1827 and 1833 Robert Stephenson was occupied in railway construction, assisting his father on the Liverpool and Manchester Railway, and laying down some minor lines. The first great work, however, for the success of which he was solely responsible, was the London and Birmingham Railway, an undertaking of high historic interest, both on account of the gigantic difficulties which were encountered in its construction, and of its being the first public iron road into London. The London and Birmingham Line was opened in 1838, and from that time till the close of his life, Robert Stephenson was engaged in a series of achievements which will hand him down to posterity as occupying the front rank among Engineers in an era abounding in men conspicuous for mechanical genius. Important works directed by his counsel, or carried on under his personal superintendence, are to be found in every quarter of the globe. Belgium, Switzerland, Norway, Denmark, Tuscany, Canada, Egypt, and India have lines of railway formed under his direction.

The works by which he will probably be best known to posterity are his bridges; among them may be mentioned the High Level Bridge at Newcastle-upon-Tyne, the Victoria Bridge at Berwick, the Conway and the Britannia Tubular Bridges on the Chester and Holyhead Line, the Victoria Tubular Bridge over the St. Lawrence River at Montreal, and the tubular bridges over the Nile at Benha and at Berket-el-Saba, the precursors of that at Kaffre Azzayat on the Egyptian

* Vide "Transactions of the North of England Institute of Mining Engineers," Vol. viii. p. 66.

Railway from Alexandria to Suez. Such are a few of the principal monuments of his genius. But his Parliamentary services, as a witness in the committee-rooms of the two Houses, were, at the time they were rendered, neither less valuable nor less distinguished, though at the present date they may be less generally known. In the two memorable contests of the Battle of the Gauges and the Battle of the Atmospheric System, he fought as he had previously fought in the Battle of the Locomotive, strenuously, indefatigably, and temperately, opposing the invincible strength of a calm judgment and lofty intellect to the brilliant subtleties and splendid daring of a worthy opponent.

Throughout his career Robert Stephenson was as popular as he was successful. Never ambitious of self-aggrandisement at the expense of his colleagues, he had the rare faculty, inestimable in those who occupy places of chief command, of selecting capable coadjutors and subordinates; and he united to this faculty a generous anxiety that his assistants should receive the full share of fame and of remuneration due to their exertions. In December 1837, as the labours of constructing the London and Birmingham Line were being brought to a close, the members of the engineering staff under his command entertained him at a public dinner at Dunchurch, and presented him with a piece of plate of the value of 130 guineas. In the same manner he was in November 1839 presented with a service of plate of the value of £1,250 by the "gentlemen who had been engaged as contractors for the construction of railways or the supplying of permanent materials." As the subscription of each contributor was limited to five pounds, this demonstration was in no respect a mere party movement, but the expression of a general and wide-spread sentiment. On the occasion of the presentation of this testimonial, he was entertained at a very numerously attended public dinner at the Albion Hotel. Besides these and many similar expressions of good-will, unsought honours were poured in upon him. In 1841 he was decorated by the King of the Belgians with the Order of Leopold, and in 1848 he was presented with the Grand Cross of St. Olaff of Norway. In 1855 the Council of Presidents and Vice-Presidents of the Great French Exhibition awarded to him the Great Gold Medal of Honour for the invention and introduction of the system of tubular plate-iron bridges, First Class Silver Medals being at the same time awarded to Messrs. William Fairbairn, (M. Inst. C.E.,) Eaton Hodgkinson, (Hon. Mem. Inst. C.E.,) and Edwin Clark, (M. Inst. C.E.,) for their respective labours of co-operation, and he was at the same time decorated by the Emperor with the Order of the Legion of Honour. In 1857 the University of Oxford conferred upon him the Degree of D.C.L. He had also for several years been a Fellow of the Royal Society, and he was a member of most of the other scientific and learned societies of the metropolis.

His connexion with the Institution of Civil Engineers began in 1830, when he became a member. He was elected a Member of Council in 1845, soon after the first radical change in the constitution of the society, to which he mainly contributed, and he continued in that position till 1848, when he was placed among the Vice-Presidents. At the Annual General Meeting in December 1855 he was elected President of the Institution, in which capacity he acted during the two ensuing years, 1856 and 1857. It is needless to dilate upon the warm interest he took in everything that concerned the Institution, his assiduous attendance, not only at the Council but at the Meetings, where he so frequently took a prominent part in the discussions, of which the Volumes of the Minutes of Proceedings give such instructive evidence. The interest he felt may be said to have

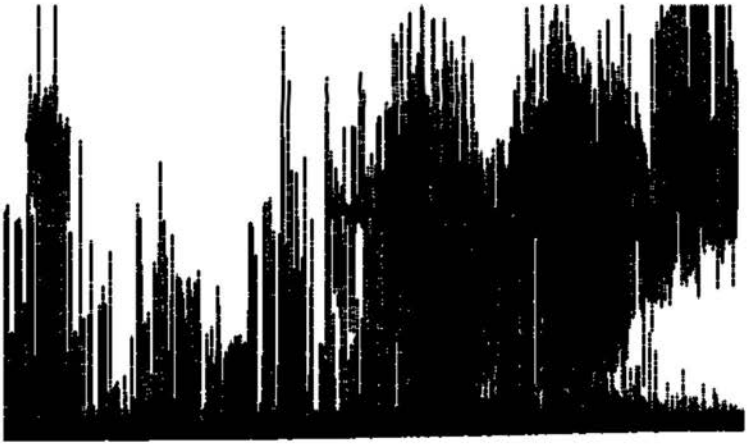
continued after his death, for amongst his legacies he bequeathed the munificent sum of £2,000 to that Institution, of which he was so distinguished an ornament.

Entering Parliament in 1847, as Member for Whitby, Robert Stephenson continued to represent that important constituency in the House of Commons until the period of his decease. In the debates his voice was not frequently heard; but on the few occasions of his addressing the Speaker on professional questions, such as that of the Canal of the Isthmus of Suez, and that of the building in Hyde Park for the Great Exhibition of 1851, he was listened to with attention, and acquitted himself with dignity and effect.

A life of severe mental and bodily exertion,—such as that led by Robert Stephenson from early boyhood to the close of his career,—makes decay anticipate old age. For the last eight years of his existence his health had, occasionally, manifested symptoms which were calculated to cause great anxiety to his friends. At no time did his mind sustain any loss of vigour; but chronic derangement of the digestive organs indicated the existence of mischief, destined to lay him in the grave, ere he should accomplish the full term of human life. At the beginning of 1859 those symptoms became greatly aggravated, and he was advised to try the effects of change of scene, combined with mental repose. To Robert Stephenson such a prescription was an impossibility; quiet he could not command. A mind habituated for nearly half a century to continual action amidst interests vast, numerous, and diverse cannot, by an effort of the will, create tranquillity for itself. In September 1859, however, he broke away from the numerous claimants on his attention, and in his yacht, "that house," as he feelingly described it to a friend, "which has no knockers," made his last voyage to Norway. Yachting was, indeed, the only recreation which he permitted himself, but even then he combined business with pleasure, performing in that manner his professional visit to several places on the Continent and to Egypt. At first he seemed to rally under the refreshing influences of repose and of the sea breezes; but soon the overpowering sense of debility and of depression returned, and the attached friends by whom he was accompanied justly entertained apprehensions of the worst results. Hastening home from Norway, where he had suffered much, he landed from his yacht at Lowestoft, and was conveyed to London, where he expired at his residence in Gloucester Square, on the 12th of October 1859, within a few days of completing his 56th year.

He was buried in Westminster Abbey on the 22nd October in the presence of not only his private friends, but also the most distinguished representatives of the literature, science, and art of Great Britain in the nineteenth century.

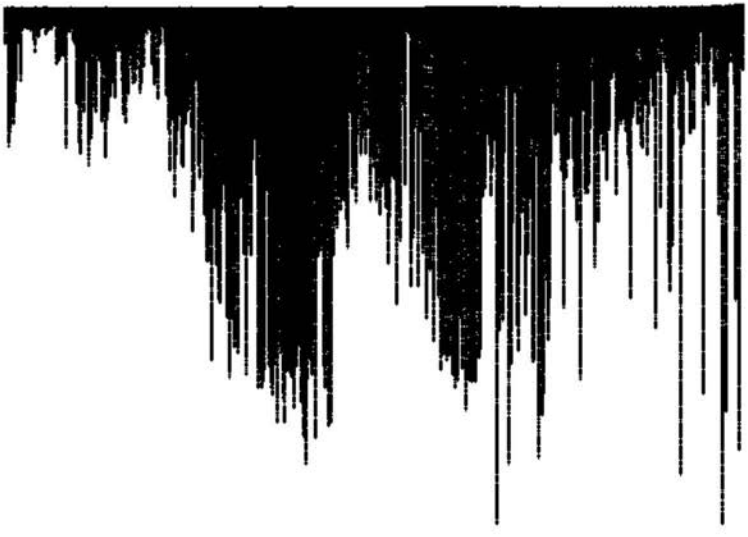
The benevolence which had, in early life, formed a prominent feature of Robert Stephenson's character, manifested itself in his later years, in a series of munificent acts towards the inhabitants of Newcastle and the surrounding district, amongst which may be mentioned his donation of £1,200 to the Memorial Schools at Willington Quay, £3,000 to the Literary and Philosophical Society, and £10,000 to the General Infirmary of Newcastle; and by his last will he bequeathed upwards of £25,000 to charitable societies and scientific institutions. Few professional men have attained such well-deserved celebrity as Robert Stephenson, and his works will remain to attest his well-earned reputation. His memory will long live in the hearts of those who appreciated and loved him for his manly qualities in private, as they admired him for his public acts and high professional attainments.



Errata.

P. 9, col. 1, line 6 from foot, *for* Bolton *read* Boulton.
„ 38, „ 2 „ 11 „ top, *omit* extensively.

Humber's Record of Engineering, 1884.



A RECORD

OF

MODERN ENGINEERING.

1864.

ADDRESS.

In compiling the second volume of the "Record," and presenting it to the engineering world, we have been greatly encouraged and stimulated to more wide-spread exertions, by the marked success which has attended the production of our first volume, and obtained for it the position of a standard work.

It was our intention to have issued monthly parts as heretofore, but the many inconveniences of that plan, added to a desire on the part of several subscribers, have induced us to adopt a different course, and publish only half-yearly or annual volumes as circumstances dictate.

It was also our intention to have given a photograph likeness of the President of the Institution of Civil Engineers, the first year of office, and, for the second year, one of a Past President, thereby forming, in course of time, a collection of portraits of the most eminent members of the profession. Owing, however, to the incessant engagements of the present President, we have been unable to obtain from him that which was necessary for carrying out our plan, but we hope to re-commence the series in our next volume.

Endeavouring to make the work as interesting as possible, and being of opinion that there was a deficiency of information relating to docks, we have selected the Low Water Basin at Birkenhead, as combining five distinct features, viz., dock and gates, swing bridge, landing stage, sluices, and hydraulic machinery for opening and closing the gates and sluices; and the Albert Harbours, Greenock, as affording a wide field for study. We have illustrated the latest practice in bridge construction, by giving the details, and a full description of the London, Chatham, and Dover Railway Bridge over the Thames at Blackfriars. We have also given four examples of railway viaducts, with their respective costs, the iron roof of the Charing Cross Station, and some details of the Dublin Winter Palace.

The letter-press is not so complete in some parts as we should have wished, in consequence of those who could have given us further information having declined to do so; however, we beg to tender our sincere thanks to John Hawkshaw, Esq., Sir W. Armstrong, Joseph Cubitt, Esq., J. F. Lyster, Esq., Messrs. Bell and Miller, and Messrs. Ordish and Le Feuvre for permitting us the use of drawings from which the plates were prepared, and also for the information with which they have kindly supplied us.

Abingdon Street, Westminster,
December 1864.

ON IRON RAILWAY BRIDGES.

It is generally admitted, that, during the last thirty years, considerable progress has been made in the art of iron bridge construction, both as regards the theoretical part, or the determination of the fundamental principles upon which the execution of the various descriptions of these structures is based, and also in the practical part or erection of the works, but it appears to us that the latter point is by no means distinctly proved, and therefore we now wish to draw attention to the details of certain modern bridges, as compared with those of less recent date.

A general survey of the road and railway bridges supported by straight and bowstring girders, which have been and are now being erected in and about the metropolis, will tend to impress the careful observer with the idea, that in these works there is more close adherence to the bare theoretical conditions than would have been permitted by what may be termed the original school of engineers, at the head of whom was Telford; and it behoves the present generation, professional or otherwise, to see that not only cheapness but also safety is regarded, by those to whom is entrusted the designing of those works, which already encircle and divide the metropolis in every direction, and furthermore almost threaten to absorb it.

Let us first consider the application of plate girders for carrying railways over roads; in this part of our subject there appear numerous objections to the system at present in vogue, the most popular being that they shorten and destroy the view in some of the principal thoroughfares, and in themselves, as it were, set at defiance the laws of beauty, presenting to the view, in many instances, a straight black band like a blot upon the scenery beyond. It may of course be argued that in most of the London districts through which the railways pass, there is not much to please the eye, but this is no reason why that little that does exist should be hidden.

But instances are numerous and constantly before us where a really fine view, and one on which much money has been expended, is at once destroyed by these legalized innovations, such as the south approach to London Bridge, and the approach to St. Paul's up Ludgate Hill, which is crossed by one of the most unsightly girder bridges it is easy to conceive, notwithstanding the powerful influence which was brought to bear against it by the city authorities, and thus it is that public taste is wholly disregarded and set at nought to accommodate the projects of utilitarian speculators. It is a mistake to imagine that elegance is incompatible with iron bridge construction, under any circumstances whatever, and it would certainly be creditable to engineers if, where they are obliged to cut off the view, they designed their bridges so as in some degree to make up for the loss.

It is, however, perhaps more with the scientific and practical points that we have particularly to deal, which are not so obvious as the architectural failings to which we have already alluded.

It must have been observed by professional men, that during the last few years there has been an increasing tendency among engineers to be guided almost entirely by theoretical considerations, notwithstanding that the fallacy of such a course has long since been very forcibly demonstrated; if a bridge, for instance, be erected capable of bearing only a dead weight, although for that purpose it may be amply strong, it will nevertheless be destroyed by vibration, if subjected to the action of loads moving at a high velocity—of course these are not exactly the circumstances of present practice, but there is an approach thereto which is sufficiently evident,—we see plate-webbed girders erected with a constantly decreasing number of stiffening plates, which in many instances are substituted by T irons at the joints, with the outer web or feather so narrow that a common cover plate might almost as well have been employed.

The result is, that the passage of a train over such girders as these will produce excessive vibration along the entire web of the girder, as there are no sufficient stiffeners to check it; the effect of such vibration is, of course, the loosening of the joints and general deterioration of the structure, so that in each succeeding year, unless some precaution is adopted to stop the mischief, the vibration will become more and more excessive. Now in former bridges, both in England and on the Continent, the girders were always amply stiffened, and thus bid fairly to outstand those of recent construction, and are decidedly more pleasant to travel upon, and it is important to consider the comfort of travellers passing over those lines of railway, now so numerous, which are carried for a great proportion of their length upon girder *bridges*, for under the circumstances of badly stiffened plate girders, the noise is increased by the rattle and jar of the structure, and it is pent in between the girders and reflected back upon the carriages, so that in its effect upon the passengers the quality is more offensive and concentration not much less than that of the noise accompanying the transit through a tunnel, where there is but the rumbling noise due to the rolling of the carriage wheels and the vibration of the locomotive, without the additional jarring of girders.

A great deal of noise may be obviated by using girders with open sides, as the lattice and warren systems provide, and although it is necessary to partly

close these sides in towns, this may be and is in some instances done with *wooden* parapets, which, instead of reflecting the sound, rather tend to deaden it and so mitigate the annoyance arising therefrom; and moreover the trussed girder, from the non-continuity of its web, is not so well calculated as the unstiffened plate girder to transmit vibration and sounds.

In the actual construction of the girders some anomalies are evident which are not easily explained away, thus, for instance, we find some of the girders recently constructed are not subject to a strain exceeding from three to four tons per square inch of sectional area, and yet we are given to understand that the quality of manufactured iron has been and is being improved in point of tenacity; now if this be true, why is more metal in proportion put into iron girders than was the custom in former years; in saying more metal, we refer to the flanges and web only, as the doing away with stiffeners to a great degree may make up for the material lost in the other parts of the bridge; the only reply to be given to the above question is that Engineers have lost confidence, either in the material or the mode of calculating its disposition. We believe that in many instances a better bridge might be made with the same amount of metal as that employed in some existing works, by merely putting less of it in the web and flanges, and more in the way of stiffening and bracing, but this would involve a little more labour, and consequently might not be so profitable to the manufacturer, and the demand at present for ironwork is so great, that the encouragement to introduce an improved style of work and designs more in accordance with old and well-tried plans is extremely slight.

It is true that among these failings there have been introduced some notable improvements, such as drilling instead of punching the plates, although it appears that there is even now some dispute as to the relative merits of the two systems, Engineers not being quite agreed as to which ought to receive the preference.

In some quarters it has been argued that in drilled plates the edges of the holes are so sharp as to tend to shear off the rivets, more than is the case when punched plates are used, but we do not feel inclined to espouse this side of the argument, and it in fact appears to us that the contrary is probably the correct view, for it is well known, that where plates are punched the holes so produced are not truly cylindrical, but conical, being smallest upon that side of the plate where the punch enters; in order to produce the best joint, the plates must be laid together with the smallest ends of the holes in contact, for otherwise the rivet in cooling would shrink away from the sides of the rivet hole, and thereby have a tendency to become loose, and when the small ends of the holes are, as above stated, in contact, there is thus a neck formed upon the rivet, whereby it is weakened and will exhibit a tendency to fracture.

As far as the actual shearing effects of the plates are concerned, it appears to us that no grave results are to be anticipated therefrom, and in this opinion we are strengthened by the results of some experiments tried some years back, which showed that the strain upon joints was borne by the friction between the surfaces in contact at the joint; this friction being of course very great by reason of the force with which the plates are drawn together by the rivets while they are cooling; the "modus operandi" of the experimentalists was as follows:—Plates were drilled for a joint, with the holes rather larger than the rivets subsequently inserted into them, so that the effect of making the joint was merely to draw the plates into contact, the work was then submitted to strains as heavy as the strength of the plates would justify, and the result showed that the plates *did not slip* so as to *bear upon the rivets*, but the entire strain was resisted by the friction between the surfaces of the plates in contact.

Another very important question to discuss relates to the mode of attaching the cross girders to the main girders in large bridges, so as to obtain a solid and secure joint, without unnecessarily wringing the main girders or subjecting them to torsion.

Undoubtedly where it can be done, the best and safest method consists in bolting the transverse girders on to the top of the girder, then the bearing of the roadway upon the principal girders will be fair and even and no torsion will result, and in addition to this the cross girders resting *upon* the main girders, they do not rely upon the bolts for their support. But in the majority of instances this course cannot be pursued on account of considerations of headway beneath the bridge, as it very frequently occurs that there is not room for a girder to be placed between the level of the railway and the road over which it passes, and yet leave the amount of headway insisted upon by parliament.

Under these circumstances, it becomes necessary to fix the cross girders to the bottom of the main girders, and there are three principal ways of doing this: first, by bolting them up to the under side of the bottom flange; second, by bolting them down on the top of the bottom flange; and third, by bolting them to the lower part of the webs. By adopting the first method, the load is fairly transmitted to the main girder, and no strain in torsion is brought to bear upon it; but on the other hand it is by some objected to on account of the fact that the entire load is thrown upon the suspending bolts, and, if they become loose or deteriorated, the safety of the roadway at once becomes seriously and perhaps dangerously impaired; never-

theless if it be properly carried out, we are ourselves greatly in favour of this mode of construction, nor can we see any serious difficulties in the way of making such joints sound and durable.

To the second method there appears to be one very serious objection, namely, that there is a tendency to twist the lower flange of the main girder, because the cross girder rests upon it on one side of the web only, except the latter be cut to allow the end of the cross girder to pass through, and this probably only makes the matter worse, by weakening the web; the tendency to torsion may be counteracted to a certain degree by the judicious application of stiffening plates at the web upon each side of the cross girder, but it cannot be altogether overcome; the one advantage of resting the cross girders *upon* the bottom flange of the main girder is that by such an arrangement no strain is thrown upon the fastening bolts, hence in any case where its adoption is proposed there must be weighed this advantage against the other evils, the conclusions arrived at will be different for different cases. Thus near stations and termini, where bridges are liable to be constantly loaded, but not usually subjected to loads passing at very high velocities, it appears very important to avoid torsion, which, from being constantly applied, would in course of time wring the girder away from its proper bearings, and, on the other hand, as the trains would *probably* only cross the bridge at very moderate speeds, the vibration would be slight, and the tendency to loosen the suspending bolts of the first method almost inappreciable. It may be desirable here to refer to the Charing Cross Railway bridge, where the mode of suspension has been adopted, using for the purpose, not bolts, but strips of angle iron riveted on to the cross girders, and also on to the main girders, thus, instead of the resistance offered to the separation of the girders being that of a screw thread, or the head of a rivet, it is the same as in the joints in the flanges, so that ample strength is secured. This mode of effecting the attachment of the cross girders appears to us to be the best, and it is in good keeping with the remainder of the bridge, which in all its details is excellently designed and constructed.

When the third method is employed, namely, the ends of the cross girders being riveted to the web of the main girder, they are virtually suspended from the top flange, but there is in this case some tendency to wring the web out of shape, and it is, moreover, somewhat weakened by the rivet-holes made for the attachment of the cross girders, hence strong stiffeners should be fixed to the web on each side of the ends of the cross girders, and, for greater security, the cross girders should also by means of bracket pieces or otherwise be riveted to these stiffeners, and thus the twisting strain may be counteracted.

While upon the subject of joints, it may not be out of place to offer some remarks upon cover plates, the judicious disposition of which so greatly enhances the strength of the bridge, whereas, if carelessly arranged they are often worse than useless. Some Engineers dispense with cover plates where there are many layers of plates one over another, using the main plates as covers, by so disposing them that no two joints fall in a line with each other; but it should be remembered that by so doing a section equal to that of one plate is lost all through the flange, so that in fact this method amounts only to making the cover plates continuous throughout, whereby usually it happens that considerably more metal is employed than would suffice in the ordinary way.

Hence the best plan is to have the main plates as long as they can conveniently be obtained, and to use the cover plates in the ordinary manner, except, indeed, they can be in one piece with the main plates, by continuing the latter beyond the point to which they would be required to bear the strain, which it must be remembered diminishes constantly from the centres of the flanges to the points at which the girders are supported.

It has been suggested, and the view is now upheld by some Engineers, that cover plates may be omitted in the case of angle iron joints; but there appears to be no reason given, except to save trouble, and this is scarcely sufficient, as in most instances the safety of iron bridges depends, in a very great degree, upon the arrangement of the angle irons. Hence if a structure of this class have no angle iron covers, it can only be regarded as a slovenly piece of work, and scarcely as a safe one.

As a rule, it appears to us that lattice and warren girders are better designed than plate girders, though it is not easy to give an explanation of the reason, except it be that in the latter the joints are more easily accessible and more simple, many of them frequently consisting of plates connected by one large joint pin, accurately fitted to the holes drilled in the plates for its reception.

In addition to the stiffeners already referred to as being necessary for the plate girders of a bridge, there is another part which needs to be well braced, namely, the platform, for if this part of the structure be in itself rigid and free from much vibration, the entire bridge will be correspondingly steady.

Bracing may be classed under three heads—square or plate bracing, diagonal bar bracing, and cubical bar bracing. The first consists of plates or gusset pieces fixed between the elements of the structure to retain its various parts parallel, and at the proper angle with adjoining parts; the second comprises the various modes of fitting tie bars from corner to corner, also producing the same effect as plate bracing, but re-

quiring a smaller amount of material to produce the effect; the third method, or cubical bracing, consists in joining the opposite angles of cubes or parallelopipedons by tie bars.

Plate bracing in platforms is very easily effected by means of buckle plates, which afford a very great amount of rigidity, if properly applied, though the method of using them, simple as it appears, is not understood in all cases. Thus, for instance, they are sometimes applied in an inverted position, that is, with the convex side downwards, this being done upon the ground of wrought iron resisting tension better than compression; but there are other points to be considered in addition to this, and one of considerable importance is, that when a tensile strain is induced upon the plates there is a tendency to draw them away from each other, and thus the bolts which hold them are strained and perhaps loosened, the inclination being, in fact, to pull the platform asunder. Then, if the plates be properly fixed, that is, with the convex sides uppermost, they will abut against one another, and there will in consequence be no strain upon the nails or bolts which hold them down. These plates thus act as struts, for which they are best suited.

With diagonal and cubical bracing matters are different, as the bars act only as ties, properly speaking, and are inefficient as struts, on account of the small amount of rigidity they possess.

These remarks, however, only apply to the light bracing used in platforms, as in trussed girders and other heavy trussed works, some of the bars act as ties, and some as struts, and others alternately in both capacities; and then it becomes necessary, wherever a bar is liable to a compressive strain, to strengthen it with angle or T iron, or by some other method which may suffice to give it the requisite rigidity to withstand the strains to which it may be liable.

In some instances, as the bridge over the Thames at Blackfriars, which carries the London, Chatham, and Dover Railway, the tops of the main girders are tied together by tie beams, whereby the vibration is very much reduced, and the structure thus rendered steadier and more enduring; but it is not in every case that these can be used, for it requires the main girders to be sufficiently high to allow headway for the engines to pass under them, and not so far apart as to necessitate very heavy stiffening girders between them.

Let us now turn our attention to iron bridges carrying roads over railways. In this case it is the interior of the bridge which principally requires our consideration, as its exterior appearance is a matter of very little importance, as railway travellers seldom have much opportunity of criticising the bridges under which they pass; we are therefore, in this case, at liberty to use any kind of girder which may be most suitable, and plate girders are in general request for the purpose. The bracing also and the disposition of stiffening plates are not matters requiring such close consideration, as the liability to vibration is less, for even on a crowded bridge, where carriages and pedestrians pass, the vibration originated in one part is counteracted, very frequently, by that arising in another, and thus the disturbing forces neutralize each other to a great extent.

In forming the roadway much may be done to deaden vibration by having a good thickness of earth upon the roadway girders or plates; but this of course cannot always be got, and moreover it adds considerably to the weight on the bridge, and in consequence needs a heavier set of main girders to sustain it, so here a medium should be sought, so as to obtain the best effect with the least amount of material.

Passing from plate and bowstring girders to the consideration of modern arched bridges, we come at once upon a much pleasanter topic, as we can look upon most of the railway bridges upon that principle with some reasonable degree of satisfaction, as they are generally of a rather elegant appearance. In support of this view, we may refer to the Victoria Railway bridge at Battersea, and that on the West London line, a little higher up the Thames, both of which structures exhibit undoubted signs of much care having been bestowed in designing them. The bracing of arched bridges is quite a different matter from that of plate and bowstring girders, for here the roadway is upon the top of the ribs which carry it, and if it is desired there can be a rib for each line of permanent way, so that by this course transverse girders may be dispensed with, and the roadway itself becomes the top bracing of the ribs; all therefore that remains to be done consists in bracing the ribs together transversely. With the change of temperature between summer and winter the crown of the arch will sink, and *vice versâ*, therefore it is well to adopt the plan used in the above-mentioned Victoria bridge, where the ends of the arched ribs are not flat but semicircular, so as to allow the bridge to accommodate itself with greater facility to the variations of temperature, for were it otherwise, when the crown rises or falls from its normal position, the angle of the extremity of the rib, changing with such rise and fall, would cause an unequal bearing upon the bed plate, and therefore an undue strain upon the arched rib itself.

In conclusion, we may remark that wherever an arch is available, it affords far greater scope for ornamentation than does a straight girder, where great difficulty occurs in breaking the monotony of the straight line, although by employing an open lattice web the design generally may be much lightened, and the effect thereby rendered more pleasing to the eye.

ON THE COATING OF IRON STRUCTURES TO PREVENT OXIDATION.

In treating this subject, it is not our intention to dwell minutely upon the chemical composition or action of anti-corrosive paints, but merely alluding generally to these points, to regard more particularly the practical results attained, and the broad principles which form the basis of a secure system of procedure, in applying the means at our disposal to effect the desired end, namely, the preservation of iron surfaces exposed to atmospheric or aqueous influences.

Notwithstanding the great importance of preserving iron structures from decay, it is sufficiently evident that chemists have not kept pace with the times; in all directions the use of iron has increased in an almost incredible degree, and yet some of our noblest structures have almost been condemned to decay for the mere want of attention to the composition of paints or coatings capable of protecting iron from oxidation; thus, for instance, it is well known that no less than twenty tons of rust have been collected from the Britannia bridge, and, in all probability, an equal amount has accumulated or fallen away unnoticed and unweighed. If such constant waste makes similar inroads upon iron structures generally, it is a necessary result that their strength is constantly reduced, and their capability for sustaining the load to which they are subjected materially deteriorated. It must not, however, be supposed that in every case, where failure of a protective covering ensues, that the fault is due to the composition of such covering; for this is most certainly not the case, as it may be due to wetness or "sweating" of the iron when applied.

If lead paints are applied to iron, it will be observed that the latter will usually oxidise underneath the lead coating, and gradually detach the latter so that it will scale off, not through its own deterioration, as it will be found to be as good as when first applied, but simply by the mechanical action of the ferruginous oxide upon it. The Great Western Railway station roof at Paddington is a good example of this, for no sooner have the painters finished at one end, than they appear to have to commence at the other.

Experience proves that the best known protective covering for iron may be formed from composition having its own oxide as a base; but the oxide itself in its native state is not only incapable of protecting the metal from external influences, but is even destructive, as may be proved by very casual observation of such works as have been exposed to the atmosphere, with iron surfaces unprotected. The sesquioxide parts with a portion of its oxygen to the sub-lying metal, giving rise to an extra formation of protoxide, and the external air supplies the loss of oxygen to the exterior coating of sesquioxide, or rust; thus it is evident that all paints based on oxide of iron may not be equally efficient, and it is the business of the Engineer to be acquainted with the relative degrees of efficiency exhibited by the various articles submitted as anti-corrosive coatings.

Considerable attention has been paid to preservative compositions by Mr. Szerelmey, who has introduced various compounds to public notice. Those are probably best known which are designed for the protection of stone surfaces; but, nevertheless, the granitic composition as applied to the ironwork of the new Houses of Parliament has principally established its efficiency.

Szerelmey's iron preservative composition.—The desiderata, which this gentleman seems to have attained, is the production of a substance which shall possess the essential qualities, first, of resisting decomposition by the acids generated in the atmosphere of a town where the constant combustion of coal is taking place; secondly, of being insoluble, and consequently not liable to be affected by any amount of rain; thirdly, of being able to resist the action of a very considerable degree of heat and cold, without which quality its utility would be confined to certain latitudes of the earth's surface; fourthly, of being so much in affinity with iron as not to be decomposed by any galvanic or oxidating action. These several objects seem to have been accomplished. The composition is not affected by being immersed, even in sulphuric acid, nor will the action of the elements at all affect it after it has been allowed to dry. The roof of the clock tower at the Houses of Parliament was originally coated with a bituminous composition, and the gilding was commenced; but it was ascertained that decomposition had taken place before the gilding was finished, and Mr. Szerelmey was applied to for some of his composition. This was supplied to the contractor, and used without the supervision of the inventor; and although diluted by the contractor with spirits of turpentine, which forms no part of the composition, and is disapproved of by the inventor, it has preserved the gilding from the action of the oxidation of the iron to the present time, a period of seven years. All the external gilding on the building has been similarly executed; in fact, all the external iron has been coated with the composition, whether gilt or not. The inventor has a modification of the composition, adapted for surfaces where a certain amount of torsion has to be provided for. The pre-

paration adapted to rigid surfaces is, when dry, perfectly hard, and can only be removed with the aid of a cold chisel. It is highly magnetic, and dries rapidly, but contains no particle of lead or other metallic substance calculated to excite an injurious chemical action with iron. It is applied in two or three thin coats after the surface of the iron has been well cleansed, and is applied forcibly down on the surface. It is of a brown colour, but may, when dry, be painted to any tint required.

Torbay iron paints, first introduced generally to public notice in 1851, but which were in use nearly two years previously, have proved practically very successful. Advantages are hereby gained in a variety of ways; not only is the iron coated with these paints preserved instead of being deteriorated, but the paint is in itself cheaper than lead paint, as, from the facility and tenacity with which it adheres, a larger surface is covered by a given quantity of this composition than an equal amount of lead would suffice for. It has been very largely used by Government in the various dockyards, and most favourably reported upon; but even this coating may be prevented from producing its usual good effect if it be not properly laid on to the surface it is intended to protect. Ordinary ferruginous oxide will take a very tenacious hold of iron surfaces, and if, by the proper admixture of suitable ingredients, the injurious action already referred to be obviated, its success as an anti-corrosive paint cannot fail to be evident.

Recently galvanized iron has been largely used for roofing and similar purposes, but without great success, for wherever it is exposed to a sulphurous atmosphere the coating is sure to be very rapidly destroyed, and that gone, the iron underneath is, of course, very rapidly deteriorated, being exposed with what is worse than no protection, as the remains of its former coating will, with moisture, cause galvanic action to commence, and thus materially hasten decay, so that the iron would in reality have been far more durable had it been merely used fresh from the rolls. A similar injurious action will not unfrequently arise when iron is coated with certain lead paints, though we do not think galvanic effects so likely in this case to make themselves evident, and in many instances oxidation, produced by the intrusion of atmospheric air under the lead coating, may, we think, have been in a great measure wrongly attributed to chemical action; and in considering the relative effects of zinc and oxide of lead upon iron, it may, perhaps, be desirable to call attention to the fact that the two latter are both of them paramagnetic, whereas zinc is diamagnetic, and known to be capable of exercising a very considerable chemical action in connexion with iron, whereas that produced by oxide of lead must be comparatively trifling.

In those instances in which iron is exposed to aqueous influences, there is of course a much greater liability to deterioration by chemical action than when the metal is perfectly dry; and in some instances the water itself may contain foreign matters in themselves exercising a destructive action. All these points must be taken into careful consideration, when deciding upon the mode of treatment to be pursued for the protection of any work having exposed ferruginous surfaces; thus, it would be useless to cover such surfaces with compositions which the circumambient medium is capable of bringing into solution either totally or partially, that is to say, either by combination with all or some of its elements.

It is a fact now established that, under certain circumstances, sea water is capable of dissolving iron; thus, if allowed to act upon cast iron, it may produce the result of dissolving out certain portions and leaving as it were a skeleton of the former mass, deceptive to the eye, because it yet retains the form and size of that of which it is the remainder, although, by the abstraction of some of its most valuable constituents, its strength and reliability is exceedingly reduced. In regard to protective coatings consisting of a mixture based on oxide of iron, these remarks bear in the following manner: it generally appears that iron, previous to solution, must be brought into the condition of an oxide, even though the ultimate compound may not be such base combined with an acid, but a haloid salt; hence, if the water, in which a mass of iron is immersed, is capable of dissolving the metal, it is only reasonable to conclude that it is capable of dissolving the oxide, and that it does in fact first oxidise the metal, and subsequently bring it into solution; hence the same medium would remove an *efficiently protected* coating of oxide with even greater facility than it would act upon the metal itself; it may appear anomalous to refer to the *protection* of protective coatings, but in fact it is not so, only the effect is produced by the admixture of ingredients in such a manner that, although the basis of the compound may not, *per se*, be capable of resisting the action of those influences to which it is subjected, yet, in combination with other elements, evil results are obviated; for if the basis itself of the coating be removed, the remaining matters will not suffice to protect the underlying metal, which will accordingly be immediately attacked and ultimately destroyed, except the paint or composition be constantly renewed, as we observe is often done.

There is also another evil to be guarded against, in the compounding of anti-corrosive paints, which is a possible liability to dissolution or deterioration of the ingredients which accompany the base; for if these be removed, one of two evils, or both, may immediately ensue; in one case, the base remaining alone exposed may yield to rapid decay, and in another it may, when

thus unrestrained, exercise on the metal, for the preservation of which it has been applied, that deleterious action to which we have already alluded, namely, the oxidation of the sub-lying metal by the reduction of the coating from sesquioxide to protoxide of iron.

These exigencies demand very great attention on the part of both engineer and paint manufacturer; for with the vast spread of iron manufacture fresh difficulties arise to be at once contended with, and there is but scant time for experimenting; and in these, as in many other similar cases, unsupported theorizing is generally useless or worse, inasmuch as its tendency is to lead to too great a confidence in results unproved, which will in all probability entail failure, and give rise to a great and unnecessary expenditure, which might have been avoided by due consideration in the first instance.

It is to the interest of manufacturers to sell such preparations as shall endure, and not to merely send forth a spurious article; for although it may take many years to prove the durability of a protective coating, yet it requires, in the majority of cases, but a few months to prove the inefficiency of an inferior composition; so long as the first coating applied exhibits no deterioration, so long will the same substance continue to be used; but when it is once discovered to be useless, as a necessary result it will cease to be favourably regarded. Also, in cases of failure, through want of care in the application of preservative paints, it is absurd to withhold from the consumer the information requisite to enable him properly to use it, for fear of the exposure of the secret of manufacture to rivals; for it matters not how good the paint may be in itself, that is in its composition, if it should *practically* prove a failure; and it were better to risk the chance of the injury of opposition, than that of total failure in exhibiting the results professed to be produced.

We have now entered at considerable length upon the details connected with the question of the preservation of iron from oxidation, and indicated the various emergencies arising; and it is certainly desirable to go a little farther in showing how these emergencies are practically met and overcome, as it is not to be expected that constructors can devote more than a small proportion of their time to this question, and moreover at present it is not needed, as preparations are available, which meet (as far as is practically possible), all the requirements of the Engineer, producing results, attested more by the facts observed, than by theoretical reasoning or voluminous testimonials.

The Torbay iron oxide paints, (as manufactured by Samuel Calley, of Brixham, Devon,) based, as the name indicates, on ferruginous oxide, exhibit properties peculiarly adapted to the purposes for which they are designed. It is necessary to be particular in indicating the composition referred to, clearly, to prevent confusion, as amongst the numerous pseudo anti-corrosive coatings introduced to the public, the proprietors of some have "accidentally" termed them Torbay paints, hence we have been careful to note particularly the one compound which has given such favourable results.

Consisting of some eight ingredients, this paint has stood the most severe tests, and, applied variously and in various colours, has given satisfaction in numerous localities, being adopted by the Gloucester Waggon Company, the Cheltenham Gas Company, the Taff Vale Railway Company, the Thames Graving Dock Company, and many railway, gas, and other companies unnecessary here to cite.

The composition should, in order to produce its best effect, be applied to the iron when new, or at all events before it is so far oxidized as to scale, for it is of no appreciable consequence, if the metal to be coated is merely slightly rusted. As regards the quantity necessary to be laid on, the Government Specifications require four coats, but Mr. Calley (the manufacturer) recommends two coats for iron, or three for wood, and own experience leads us to conclude the latter to be sufficient, as we have seen a case where only one coat of the protective paint was applied to the exhaust pipe of a steam engine, and, after 18 months' exposure, appeared as good as when first applied, although it had been subject to trying exposures, aided by the heat, which, of course, at intervals acted upon the pipe, nor were any symptoms of scaling off discernible.

Let us now compare the cost of the Torbay iron oxide paint with the ordinary red lead paint, where, first, the matter is simplified by the price being about the same in both cases, but, in the second place, 60 lbs. of the Torbay iron oxide paint will efficiently cover as much surface as 112 lbs. of ordinary red lead paint, and will require less labour on the part of the men applying it, as from its peculiar properties it adheres with great readiness and pertinacity to the surface of the iron.

To ensure success, Engineers must not only specify for the description of paint they wish used, but they must see that it *is* used, as we have recently had three cases come under our notice, where Calley's "Torbay iron oxide paint" was specified, and spurious compositions substituted; in two out of the three cases, an inferior composition was used, and, in the third case, a more expensive though inefficient one was substituted. Care must be taken not to use lead paint for the first coat, or the subsequent coats of the Torbay iron oxide paint will scale off with it, and will not have the desired effect.

In conclusion, let us observe, that the question we have herein discussed appears frequently to have been much mystified, either by want of observation on the part of consumers, or of candour in the manufac-

turers; whereas, the subject itself is sufficiently clear; the evils with which we have to contend are evident; the means of overcoming them are at hand; and it only remains for those, to whose care the erection or charge of iron structures is confided, to be particular in the selection of the right means to attain the desired end;—the preservation of the metal at minimum cost, which may be done by adopting the system already proved efficient, instead of being led into error by unsupported pretensions or untried theories, which are in themselves vain and in practice unavailing.

ON THE ECONOMY OF STEAM MACHINERY.

FEW DISCOVERIES, ancient or modern, will stand in comparison with that of the dynamic value of steam, as applied to the useful arts, which has, in the last century, revolutionized the whole of our manufactures, and raised England from being helpless in engineering matters, to a position which is unrivalled. Formerly, Holland and Flanders supplied both Engineers and workmen to Britain; now we export machinery to those countries; our early embankments and extensive drainage works were planned and carried out by Sir Cornelius Vermuyden, and other Dutch Engineers, but in the present day English pumping engines drain the fields of Holland, and thus it has been that the latent faculty, invisible for centuries in our nation, when once awakened, soon in its development outsped that which had called it into active existence;—beginning with sceptiesm, we have progressed to perfect faith in the useful application of the natural forces, and cannot now rest satisfied with what has already been accomplished, wonderful though it appears when the shortness of time is considered. It is impossible to attribute many of our inventions to single individuals, having arrived to their present state of development through the successive life-long labours of some of the greatest intellects that ever enlightened the world, and perfection is not yet attained, nor can be, if ever, for many generations; "*ars longa est, vita brevis.*"

Some of the old engines of Newcomen, rough though they were, both in design and workmanship, gave results, showing an amount of economy which might be worthy the attention of more modern Engineers; and when it was rendered automatic by Potter's invention of the plug rod, to work the valve gearing, there was, comparatively speaking, but little fault to be found with it.

However, James Watt took the matter in hand, and produced an engine which seemed to bid fair to supersede all the other pumping machinery, then in existence, so far superior was it in point of economy to any other then working; thus the Bolton and Watt engine gained ground, doing, in some cases, double duty, in comparison with its predecessors; and in London its position appeared to be immovably fixed, holding, as it did, the good opinion of the most eminent Engineers of that day. But the time was not very far distant when it was to give place, not to a new invention or new form, but rather to the old one in an improved condition, for the Cornish Engineers had been slowly and silently working out their own ideas, and though not urging very much the extension of the circle in which their engine was employed, yet, fully appreciating and availing themselves of the practical economy which did then, and yet does characterize it. It is a significant fact that this engine is known only as the "*Cornish engine,*" and not by any individual's name, and may be taken as evidence of the number of inventors who were concerned in its improvement. At a time, however, when there existed in London much prejudice against the Cornish engine, Mr. Wicksteed was commissioned to examine it and report upon its efficiency. He proceeded to Cornwall for the purpose, and the result was, that an engine at work there was pulled down and brought up to the East London Waterworks, where it has been doing duty ever since, being known as "*The* Cornish engine," and it is a notable fact, that in a fair trial, extending over a considerable period, the economy of this engine has never been exceeded but by one, namely, the "Wicksteed engine," erected at the same works, and by the Engineer whose name it bears; the difference, however, between the two engines is not very great, the "Cornish" engine having raised 106,000,000 pounds one foot per 112 pounds of coal consumed, and the "Wicksteed" 109,000,000 pounds for the same amount of fuel consumed; and even now we find the engines reported in Cornwall do not exceed from 70,000,000 to 80,000,000 pounds raised one foot per 112 pounds of coal consumed. This would be equivalent, in other words, to a consumption of about 2 pounds of coal per horse power per hour for the "Wicksteed" engine. Some statements have been made, in which the consumption of fuel for certain engines has been quoted as low as 1·08 pounds of coal per horse power per hour; but it must be noted, that such results have not been attained from trials of *long duration*, and the value of *short* trials is too well known by Engineers, to need any comment on our part; but it may not be out of place here to mention, that, on one occasion of a trial, matters were worked

to such a nicety, that when the weight of the remaining fuel had been taken, it was found that the consumption per horse power per hour when calculated out was a little *less* than *none at all!*

Before quitting the Cornish engine, it is necessary to remark upon the extraordinary high duties reported previous to its introduction into the metropolis; for these were based upon erroneous data, the amount of water lifted being calculated from the contents of the pump barrel, whereas the full bore of water was not thrown up in those times, as much as one-eighth being lost at each stroke in some engines, and one-tenth in many, during the closing of the suction valve, then of the form known as the "butterfly valve," which, by reason of its great surface, would not fall through the water quickly enough to retain all that had passed through it, and then to facilitate its fall before the water should, by falling with it, create great concussions, air was admitted under the valve. This difficulty was, however, overcome by Mr. Wicksteed's introduction of the Harvey and West's valve with a double beat, which, being partially equilibriated, fell noiselessly, and closed the suction pipe, as soon as the pump plunger had reached the top of its stroke; and an observer may now see, that in engines fitted with this valve there is, in fact, no loss of water, for the plunger will take its bearing, without falling at all, whereas when the old valves were in use it would settle 12 or 18 inches, before commencing its effective outdoor stroke. About the same time that the Cornish engine was being thus established amongst Engineers, George Stephenson was busily engaged in the endeavour to make the locomotive engine sufficiently economical in working at high speeds to enable it to compete with the stage coaches; but the difficulties which beset him were so numerous, that 12 years elapsed from his commencement to the time when its practicability was publicly manifested; and even at the present day, the locomotive, notwithstanding the high state of perfection to which it has been brought, is rather voracious, so that there is still much room for improvement.

Careful research shows that the economy of steam engines, taken *per se*, can be accurately anticipated, and it ought, rightly speaking, to be taken independently of the boiler; that is to say, the economy of the engine should be stated according to the *water* used, and not according to the *fuel*, for if both engine and boiler are taken together, it is difficult in cases of insufficient economy to decide in which the error lies, —the efficiency of the boiler is in proportion to the quantity of water evaporated by a given quantity of fuel. Supposing this method to be followed, the process, as far as regards the engine, is simple enough, and it is to the boiler that our attention must be turned; and it is a matter often commented upon, that Engineers do not appear to have paid so much attention to boilers as they require, for it is there that we have to deal with the subtle element caloric, and catch it as it flies. The steam once formed, the management of *that* is practically clear enough. In the furnace is probably to be found the most serious defects which now impair the economy of the steam engine, but it does not at first sight appear very easy to detect them, although the nature of fire and flame is not so mysterious as many deem it: but there is one notable fact strikes us in comparing steam and caloric as we apply them, the former is pent up under exact control, the latter is almost free to wander according to chance, only slightly constrained, to pass through certain flues in order that a portion of it may be arrested. When we can control the caloric developed from fuel, as we control steam, then will the boiler be as perfect as the engine; but, according to the present construction of furnaces, a large quantity of heat is wasted, in maintaining the draught which carries it away before it has done its duty; but of this, more will be discussed presently. Numerous endeavours have been made to secure the more effectual absorption of heat from the passing gases, in the flues of steam boilers, but the results show a loss of economy. In the single flued and old waggon boilers, with slow combustion, from 8 to 10 pounds of water were evaporated per pound of coal consumed, but in modern locomotives, the evaporation is about 6 pounds of water per pound of fuel consumed; this has reference to continuous working, not to those numerous trials, where so great economy has been effected, although those who make the experiments do not take care to inform the public, that the boiler tried is probably only worked to about one-fifth of its capacity, and very likely without the blast. If a test is made, it should be upon a locomotive running and worked up to the highest point; for it is comparatively easy to obtain good results when the combustion is slow; but what is so much needed is quick combustion with economical results, and this has not yet been attained so far as the public are informed. It would be interesting, had we the space at our disposal, to enter into the commercial advantages which would accrue from the saving, say, even of 12 per centum of the fuel consumed by our railway and steam navigation companies; but this would not afford the practical information, as to how such a result might be attained; the only mode is to consider the circumstances of combustion, as it is, and as it should be, and thus we may arrive at a practical conclusion. Many modes have been brought forward, and one proved successful, and that one is in accordance with the reasoning of the matter, although it may have been accidentally stumbled upon.

Let us consider the ordinary circumstances of com-

bustion in the furnace of a steam boiler. The furnace having been lighted, the draught is set up, and air in large volumes passes through the fuel; as the heat becomes more intense, the air passes through quicker, being more immediately heated on contact with the incandescent fuel, and thus the more fiercely the fire burns, the greater is the *proportionate* quantity of air passing through it. The result of this rapid passage of the air is, that the duration of its contact with the fuel is not sufficient to allow more than a very small proportion of its oxygen to be withdrawn, and thus the combustion of the fuel is imperfect, and gases and carbonaceous smoke pass from the furnace unconsumed, and, when they reach the flues, they, although surrounded by a more than ample supply of oxygen, are then cooled down below the temperature at which they can enter into combustion, and thus the caloric, which might have been developed from them and usefully employed, is practically wasted, double harm being done, because that which should have been applied to an useful purpose, goes forth to contaminate the atmosphere.

Under these circumstances, probably the amount of atmospheric air, passing through the furnace, is from 10 to 15 times the quantity actually required for purposes of combustion; and, as all the air thus passing out through the chimney must carry away with it a large amount of caloric, it is at once evident, that here alone is a very serious cause of inefficiency in steam boilers, and so we may account for the fact, that, while the theoretical evaporation of coke is about 15 pounds of water per pound of coke, yet the practical evaporation does not exceed from seven to eight pounds of water, although in this case there is no smoke evolved to account for the loss. The conclusion arrived at is therefore that the lost or waste of caloric arises conjointly from the two following sources:—First, the large quantity carried off by the excess of air passing through the furnace, and second, the inefficiency of the water surface to absorb the heat from the passing gases; and so long as the present system is in vogue, so long will these difficulties impede the progress of economy in working the steam engine, for in the ordinary way, trial to stop the evil will only increase it, for if we slacken the draught, the fire dulls, and the gases being less hot their caloric is less rapidly absorbed from them.

When the fuel is rich in hydrocarbons, the greater the unnecessary excess of cold air introduced into the furnace, *the greater will be the quantity of smoke* evolved, as the cooling of the gases will proceed more rapidly; but of course the exact amount of heat-giving fuel, thus lost, will depend upon the composition of the fuel, the loss being less in proportion as the quantity of carbon exceeds the quantity of the hydrocarbons, and *vice versâ*, hence, in very badly constructed furnaces, coke is the most economical fuel to use.

From the foregoing observations, the following results may be deduced:—It is desirable to retain the atmospheric air in contact with the fuel, until all its available oxygen has been absorbed, or to approach as nearly to this result as possible; it is also desirable to retain the heated gases in contact with the boiler flues, until all their available caloric has been absorbed by the water.

Let it be granted, that in a particular case the air *is* retained in contact with the fuel, until all its oxygen is absorbed, then will the smoke be consumed because there is a supply of *hot* oxygen in contact with it, and, when the gases thus heated are brought into the flues, their excessive heat (having in a small bulk the same amount of caloric which is ordinarily carried away by a large amount of air), imparts to them a tendency to yield it quicker to the absorbing surfaces, so that they give up a maximum quantity of heat, the remaining products of combustion may then be suffered to escape.

The important point to be determined is, what would be the amount of saving in the foregoing instance. From calculation, that due to saving in the heat carried away ordinarily by the excess of air, would amount to about two-thirds of the fuel; but that saved by the consumption of the smoke is not very easily determined.

Let us now enter upon an account of the mode recently adopted to carry these principles into practice, and see how far they confirm the anticipations of theory; for thus are we enabled to determine how much reliance may be placed upon theoretical speculations, and thence we have a criterion, whereby to regulate our future movements, and further improving the process and rendering it more universally applicable.

A method has recently been patented to enable practical advantage to be taken of the principles above enunciated, and, as far as it has yet been tried, the results are very satisfactory. The preliminary experiments were conducted as follows:—In the first place, a small gas stove was selected for experiment, and the air entering it was retained in contact with the burning gas for a longer period than usual, by partially closing the flue from which the products of combustion escape. It was observed, that, as the flue was thus gradually closed, the gas flame continued to *shorten and grow more intense, thus clearly proving* that quite enough oxygen was admitted to effect perfect combustion; but the gas, not having to rise, as it were, in pursuit of oxygen in the passing draught, the combination of the two took place in a smaller space, and more perfectly; also, on account of the gross quantity of air admitted being less, the tempe-

rature of the stove rose in a corresponding degree; thus, at the commencement of the experiment, the temperature of the apparatus was 270° Fahr.; and, as soon as the flue was closed so as to reduce it to about one quarter of its normal area, the temperature rose to 600° Fahr., where the trial so far terminated, as the mercury in the thermometer would not admit of a higher temperature being recorded. Thus was found practically the pressure requisite to produce perfect or very nearly perfect combustion of the gas, with the consumption of a minimum quantity of air. This experiment is not, of course, capable of being referred to, except as a proof of the accuracy of the reasoning upon which the process is based, and thus far it appears to us to be quite satisfactory.

The next experiment tried, referred to the smoke-consuming qualities of the process, rather than the question of temperature; but it will be seen, that the results were exactly what might be expected from the last trial.

An ordinary square stove was taken, fitted with a short flue bent at right angles, a fire having been made within it and urged, large volumes of smoke poured forth, but when the end of the flue was one quarter closed, the smoke and flame diminished, retiring within the flue; and from that point, as the flue was gradually more and more closed, so the flame retreated further down the flue, until, when the flue area was reduced to one quarter its normal size, the combustion was entirely confined within a small space. Thus it was proved, that, by the adoption of this process, the smoke was entirely consumed, thereby, of course, effecting a very great saving in fuel.

The third trial comes more nearly in its conditions to the circumstances of practice, and may be said to be a very fair criterion for us to go by. An agricultural boiler of about six horse-power was, in this case, the subject of experiment, the mode of which was as follows:—First, the boiler was filled with cold water, and the fire being lit in the ordinary way, the water was heated, and steam raised to a pressure of five pounds per square inch; the consumption of fuel to effect this was 14 stones weight of coal; the boiler was then emptied and cooled, and the chimney being removed, was replaced by a lightly loaded valve, which would, of course, produce the requisite resistance to the draught, and so cause the fuel to burn under pressure. The fire-grate was partially bricked up, so as to reduce its area very considerably. Air was supplied to the fuel by the aid of a pair of smiths' bellows, and thus the experiment proceeded. Cold water was, as before, heated, and steam raised to five pounds pressure on the square inch, and this time the consumption of fuel only amounted to four stones weight of coal, or two-sevenths of that required in the ordinary way; and although the size of the grate was reduced, the effect was produced in a much shorter time than by the original mode.

The advantages here arrived at are evidently two;—retaining the air in contact with the fuel until perfect combustion is effected, and the heated products of combustion in contact with the boiler flues, until nearly all the available heat is withdrawn from them. The gases issuing from the flue valve may be passed through water, and discharged into the air direct, and thus the necessity for a chimney shaft is avoided; or, if in a factory, these gases may be circulated in pipes to warm the building.

In the fourth experiment a portable engine was used, with an old air pump attached to it. The pressure was first raised in the ordinary way to five pounds per square inch, to enable the engine to be started; then, with the engine working and the cold-water pump turned on, the steam pressure rose in five and a half minutes to 20 pounds and in seven and a half minutes to 40 pounds per square inch. The trial was then terminated, as the rivets in the boiler were already starting, and it was not considered safe to load that boiler further.

These experiments appear sufficient to establish both the economy and practicability of the patent method, as well as to demonstrate its scientific accuracy.

The power, requisite to feed the furnace with air, will amount to from two to four per centum of the horse power of the engine; and the amount of fuel saved will, from the foregoing remarks, be sufficiently large to render this item entirely unworthy of serious consideration.

In conclusion, the only point remaining for discussion is the relative cost of the fan for supplying air, and the saving by doing away with the chimney, these relating to first cost.

HARBOURS, PORTS, AND BREAKWATERS, MODERN AND THEORETICAL.

In the preceding article on Harbours, Ports, and Breakwaters, in volume for 1863, we have, by way of introduction, taken a rapid survey of some of the most important marine works as known to the ancients. The check to civilization, spread over the world by the invasion of the Goths, and the decline and fall of the Roman Empire, was only gradually remedied by the spread of Christianity; and it was

many centuries before society improved sufficiently to produce any works of a commanding nature. To travel through the history of this resuscitation, and of the renewed application of wealth and science to the formation of harbours and breakwaters, is far beyond the limits of a work of this kind. We shall therefore at once proceed to the notice of this branch of engineering as at present practised, illustrating the several axioms which the experience of modern investigation has laid down, by a detailed explanation of the plans, &c. of several harbours and other structures of a similar character, the peculiarities of which are best suited to exhibit them in operation.

To say, that of all the branches of engineering there is none which furnishes so uncertain a basis as that of designing and constructing harbours, is very trite. The Engineer, who undertakes such a task, will ascertain the fact in the very first steps which he is obliged to take; and although we will presume that he may have the modesty to look about him for experience in works already constructed of a nature similar to his own, yet, when so many elements enter into the composition of the work, he may ring the changes on them, as on a chime of bells, for a long time before he arrives at the exact arrangement which he seeks. Another difficulty which besets the designer of a harbour is the fact that his work is for the use and protection of a scientific profession, with the intricacies of which he cannot be expected to be familiar, and concerning which he must be dependent on the information of others. Of little avail is it that he construct a harbour, the interior of which may be safe and commodious, if the approach to it is so beset with danger (and this is not altogether hypothetical) that the mariner prefers braving the buffeting of the waves to seeking the tranquillity that is offered him. But this is not all; he has to contend with opposing interests, and frequently with financial difficulties, and, moreover, he has frequently to choose between conflicting advantages, or even between two evils. This difficulty was experienced by Mr. Smeaton, who says in his report on the harbour of King's Lynn, where it was required of him to devise some means to check the strength of the tide, "Too great tides may be a partial and temporary evil, but it appears to me in the present case a fault on the right side; and it seems that in this, as well as many affairs of human life, the judgment consists in choosing *the least of two evils*;" and in a subsequent paragraph of the same report he also lays down the following very sound principle, "Leave nature to herself while tending right, it is time enough to help her when we are sure she is going wrong."

We will attempt, in the following pages, in as brief a form as possible, to put together a few leading principles which the Engineer may find it useful to bear in mind whilst he is designing his work; and it will, perhaps, be the most ready mode of doing this, to recount, first, the different descriptions of marine works which are comprised in the terms harbour and roadstead, and then the different elements and operations of nature, with which the Engineer may have to deal. Having done this, we will endeavour to illustrate them by the description of some characteristic works.

Harbours may be primarily divided into two classes,—natural and artificial; and these two main classes may each be divided into several branches, according as they are more purely the result of natural geological features, or are partially or entirely indebted to artificial means, for affording protection in gales of wind. There is likewise the commercial element to be considered, where, independently of protection from the storm, it is required that facility should be afforded for loading and unloading cargoes, and executing any repairs that may be found necessary in vessels using the harbour.

We will class harbours in the following manner:—

1st. The deep-water roadstead. Many roadsteads will come under this head which are the entire work of nature, such as Portsmouth, Falmouth, Toulon, Brest, &c., and the question may suggest itself to the reader, "What have they to do with engineering works?" The answer is obvious. They are the great school in which the Engineer is to learn the fundamental principles upon which he proceeds. Look, for instance, at Portsmouth. There you have a bay most effectually shielded from the raging of the ocean by that natural breakwater the Isle of Wight, and accessible from either end; whilst the tide or tides, for there are several of them in different parts of the roadstead, having a free passage, prevent the deposit of silt, and preserve a deep water channel, suited to the riding at anchor of ships of every size.

The artificial roadstead may be effected in several ways; either by placing a breakwater in front of a natural indentation of the coast, or expanded mouth of a river; or by running out a pier or jetty from an abrupt headland, so as to shut it in either partially or totally from all winds which have what is technically called much "fetch," that is, distance of open sea to blow over.

2nd. Navigable rivers. Engineering works are principally required in harbours of this description to prevent the formation of bars and sandbanks, to preserve a navigable course, and for fitting it for commercial purposes, for which engineering works may be required, in order to obtain still water at the landing quays.

3rd. Harbours of refuge, where little or no assistance can be derived from the natural formation of the

coast. These will consist of deep-water harbours, tidal harbours which are dry at low water, and such as are *partly* dry and partly submerged even at low water.

4th. Simple piers or jetties, used for the embarking and disembarking either of passengers or goods, and which, if built of solid materials, may generally be so arranged as to be a protection from prevailing winds.

5th. Quays or wharfs built parallel with the shore, and having no reference to protection from winds or waves, but serving simply for more convenient embarking and disembarking in moderate weather.

Having enumerated the different classes of harbours, we will now state the different elements which are instrumental in marring or making a harbour for either refuge or commerce.

1st. Geological formation of the immediate locality, and of the adjacent country.

2nd. Formation of the bottom, both as to shape, consistency, and depth beneath the water.

3rd. The vertical and horizontal formation of the coast.

4th. Prevailing winds, and length of fetch.

5th. Nature of waves on the coast.

6th. Tides.

7th. Currents.

8th. Proximity of materials suitable for marine works.

9th. Existence of depository matter, and its probable amount.

We will first go into some details of these elements, and then speak more fully on the different kinds of harbours.

Before we proceed, however, to enlarge upon each of these heads, we will premise that it is not safe to rely implicitly on general principles. The operations of nature, if not singly, at least combined, exhibit themselves in so many forms that general principles may require to be modified by local circumstances. We would also advise the Engineer, in his search after examples of works similarly circumstanced to those which he may have in hand, not to neglect the study of unsuccessful, as well as successful constructions. The saying is certainly true of engineering, if not of the ordinary operations of life, that we learn more from our failures than from our successes. The man who builds redundantly and extravagantly may remain in his error for years, but the man who errs through a weakness of structure or neglect of precaution which leads to disaster, will scarcely fail to improve in any subsequent attempt. The great object in studying precedent works is not so much to imitate their mode of construction as to observe the principle upon which they have been designed, and then carefully to mark the result. This examination will show that where works have failed to accomplish their end, or probably have even done mischief, it has generally resulted from the designer having worked in opposition to nature's laws, rather than having courted her assistance; and it will not unfrequently be manifest that where expensive works have failed from this cause in one place, the desired result has been accomplished in another by the most simple means, aided by the unerring assistance of nature. This is a study of a somewhat tedious character, for the operations of nature, though irresistible and persevering, are sometimes very slow. We are therefore under additional obligations to those scientific investigators who have furnished us with descriptions and plans of the coasts and harbours where engineering operations have been periodically carried out during a series of years.

We will now resume our investigation of the several elements which enter more or less into the construction of all marine engineering works, and with which the Engineer will do well to make himself thoroughly acquainted before he forms his plan.

I.—*Geological Formation of the immediate Locality and the adjacent Country.*

This subject must necessarily form the basis of every harbour work.

Could the Engineer but secure himself against the various casualties and difficulties which obstruct his path, arising from the disintegration and reformation constantly going on in the component materials of the globe, a large amount of the difficulty of his task would be removed. Nature exhibits to us the paradox that her inroads from the action of the sea take place where the bold cliff presents a face of rock and stone to resist her blows, and that where the low flat coast seems constantly in peril of being overwhelmed by the waves, there, by the gradual and sometimes almost imperceptible deposit of sand and shingle, her force is not only checked, but she is steadily driven back, until new continents are formed, and new appliances are continually called into action, to enable what were once sea-side towns to maintain their connexion with the ocean. Thus Sandwich in Kent, which was originally a long shore town, is now comparatively inland; and Lydd, which was formerly a port, is now completely surrounded with shingle which constitutes the spit called Dungeness. The lighthouse on that point, when re-erected in 1792, was 100 yards from the sea, and at the last survey it was 218 yards distant. The bank had advanced 118 yards in 47 years. Winchelsea castle and old town, which were destroyed by the sea in 1250, are now upwards of 1¼ miles from the coast, which is almost entirely composed of shingle. Pevensey, formerly a port, is now abandoned. The vicinity of cliffs, formed of stratified rocks of considerable variety of hardness, will indicate a coast, subject

to continual wasting away by abrasion and the action of land springs. The latter cause of decay indeed sometimes being more active than the fury of the waves, by gradually loosening and washing out the softer strata and leaving the cliff undermined. The most serious and most expensive obstruction to ingress and egress of Dover Harbour was caused, previously to the construction of the new pier, by the fall of the chalk cliff to the westward.

Considerable masses are occasionally detached and fall into the sea. This for a time acts as a groin, by stopping the progress of the shingle along the coast, but after a time the constant action of the sea washes away the chalk, thus disengaging a large quantity of flint stones with which the chalk is thickly studded, and at the same time releasing the shingle which has been accumulating behind the fall. Whenever this took place the necessity again arose of continual flushing to keep the mouth of the harbour open. It has been a subject of much discussion how far groins tend to impede the progress of the shingle along the coast, and at what depth the action of the waves fails to move it. That the erection of groins is only a partial remedy is quite certain, for no sooner is the upper portion of the groin full than every successive wave throws it over to the next bay, nor would it be possible without incurring very serious expense to carry any groins into such deep water as to prevent the shingle from passing round their ends. It remains to be seen how far the new mole will answer this purpose. The dip of the stratification on a rocky coast must be also correctly ascertained, inasmuch as they will frequently, when submerged, have a great tendency to augment or moderate the seas which pass over them. Sir Henry de la Bèche remarks, in his Manual of Geology, that a skilful Engineer could not have protected the coast better than has been accomplished by the dip of the strata of the slaty rocks in some parts of the southern coasts of Devonshire and Cornwall. In this case the dip is to seaward. Of course the reverse of this will result where rocks, either from their dip or peculiar position, tend to the accumulation rather than the breaking and dispersion of the waves. As a general rule, all ledges of rocks, running parallel to the line of the works, have a tendency to shield them from the waves, but such as cross them at an abrupt angle produce heavy and dangerous breakers. Stratified rocks sometimes exhibit layers of clay or other soft material, which is easily acted on by agitated water; and where this is the case the Engineer must be careful how he trusts his works on what appears to be a rock foundation.

The above remarks apply principally to harbours of refuge on an exposed coast, but the Engineer will as frequently be called upon to create or improve what may be called inland harbours, or such as consist of adapting a tidal or navigable river to the purposes of commerce. In this case, a study of the surrounding geological formation will be very useful. The character of the river, which runs into the harbour or estuary, may be judged of with considerable accuracy by studying the character of the watershed which feeds it, not only in the vicinity of the portion of the river which is to be used for harbour purposes, but to the extremity of the feeders. Perhaps the most troublesome of all geological formations, from which a navigable estuary can be fed, is sand, sand rock, which is constantly supplying sand to the streams by decomposition, or earth containing sand in any quantity and subject to disintegration by the action of the weather. This investigation should comprise not only the nature of the soil on the banks of the streams, but over the whole surface which drains into them; for it will be found that the action of the elements has a more disintegrating effect upon some rocks and soils, than the action of the streams. The plough in turning up the furrows, and exposing considerable surfaces to the action of the rain and wind, is one of the great causes of supply of sand to streams, as may be easily ascertained by inspecting land drainage watercourses after heavy rain.

II.—*Formation of the Bottom, both as to Shape, Consistency, and Depth beneath the Surface.*

This investigation comprises, in the first instance, the formation of a correct chart of soundings over the ground to be compassed by the works, and that of the immediate vicinity. To this extent, it will be advisable to take the soundings in direct lines, so that sections of the bottom may be drawn, and a regular contour map of the locality constructed. A map of this description will greatly facilitate the formation of a correct judgment of the most advisable form of works, as it will make the shape of the bottom and its trending obvious at one view. There are various ways of executing this part of the work, dependent on the amount of accuracy and detail which may be required. These form part of the duties of the marine surveyor, and would be too lengthy to detail in this article. But besides the plan of the immediate locality, good charts must be consulted, and inquiries made as to the nature of the bottom over a wide circle to seaward, for upon this head depends the liability of vessels dragging their anchors, or, what is still worse, should the ground be rocky, breaking their anchors, or being compelled to slip their cables. It will also point out to the Engineer the anchoring grounds which will be generally resorted to, the direction from which vessels in distress are most likely to approach, and how the harbour may be most easily and safely entered from those directions, during the prevailing

winds. A rocky bottom is that which will be avoided, if possible, by vessels wishing to anchor, either to wait for the change of the tide, or for a sufficient depth of water to enter the harbour. A bottom composed of soft mud or a deposit of decayed vegetable matter, will not afford sufficient tenacity to hold the anchor in heavy weather, and if not avoided by vessels may result in their fouling one another, and eventually seeking the shelter of a neighbouring port, in which they may repair damages. A bottom composed of firm sand, or sand mixed with ouze, or of clay, is the one which will always be preferred.

In the evidence given before the Committee of the House of Commons, on the advisability of establishing a harbour at Ramsgate, it was stated that, "Great ships in the Downs are obliged to ride in a bad road to be out of the way of the small vessels, which commonly lie in the small downs, and those small vessels being ill furnished with anchors and cables, frequently break loose, and drive upon the large ships, which then run foul of each other; whereby sometimes a whole fleet is set adrift," and it was likewise stated that Ramsgate was the most suitable position for the harbour, because "it was right in the lee of that road" (the Downs), "with such winds as produced that distress, and at such a proper distance, that after driving or breaking loose they had time to get under sail" before making the harbour. This will show the necessity, when designing a harbour of refuge, to consider well the nature of the bottom in the direction principally of the prevailing wind. It will be also very necessary to observe and note at what depth and position mud is first found, as this will be a good indicator of the size of the waves that may be expected, but this will be more particularly spoken of when considering the subject of waves.

III.—*Vertical and Horizontal Formation of the Coast.*

This inquiry will be principally requisite, when selecting the most suitable spot for a harbour of refuge. Commercial harbours generally have their position determined by the existence of a town or river, or the immediate proximity of a manufacturing district, and the form of the coast is not therefore so necessary to be studied; but, for a harbour of refuge, it is of the greatest importance. Mr. Calvin, R.N., in his report to the Admiralty, on a harbour of refuge for the east coast of England, says, "A vessel's liability to be driven on shore by an on-shore gale of wind depends principally on the configuration of the coast abreast; for instance, if she is opposite a salient seaboard, or one which recedes from a given line on either hand, there is no risk whatever, as the land may be cleared either way with a flowing sheet. Abreast a straight or direct line of coast there is danger of being stranded, and it requires promptitude at the beginning of a gale, and a well found and powerful vessel, to gain and maintain an offing under such circumstances. But if a gale finds a vessel within a line joining the horns of a bay, then the danger of being stranded becomes imminent, and in the majority of cases is nearly certain, unless there be a harbour under her lee which would admit her." The greatest requirement, for this description of harbour, is therefore in a bay which it is necessary to visit or cross, and which is subject to on-shore gales. Provided that a harbour of refuge or a commercial harbour, which, from its facility of access and depth of water, is adapted for a harbour of refuge, is to leeward of the prevailing winds, it is an advantage that it should be at the extreme end of the bight, and at some distance from the anchoring ground or from the roadstead contiguous to a commercial port of small depth of water; but, in the case of harbours of shallow water, which are only available at or about high water, the further they are embayed, the more dangerous they become, as vessels in order to reach them must place themselves in positions from which, should a gale spring up, it would be impossible to escape. Mr. Calvin calls harbours with a depth of water at low tide ranging from 1 to 8 feet "dangerous decoys."

IV.—*Prevailing Winds and Length of Fetch.*

The term "fetch" is used to imply the length of sea, in a direct line, over which any wind can approach a coast or harbour uninterruptedly.

The mariner considers the wind in a twofold light. It is the great agent through whose help he carries on his trade, but it is also in its angry mood an enemy which drives him to destruction. To the Engineer, it has not so varied an aspect. It neither aids nor retards him in its intervals of tranquillity, but all his efforts and ingenuity are directed to ward off its power and guard against its destructive effects. One of the earliest inquiries of the Engineer, when about to form a design for a harbour or breakwater, is the direction from which the wind usually blows, and the point of the compass from which the most violent winds and the most destructive waves are experienced. This point will usually be found to be that which has the greatest fetch, because that is almost certain to be the direction from which the heaviest waves may be expected.

The velocity of the wind varies from 1 to 18 feet per second, and its force varies from ·006 to 5 pounds per superficial foot. Inquiries of any of the seamen who frequent a port, or the coast on which it is proposed to construct one, will inform you as to the effects of heavy gales, their frequency, and the direction from which they usually come; but this information will not be sufficient for the Engineer, because

the greatest fetch may not be in the direction of the prevailing wind.

Besides these gales, which recur several times, there are no parts of the world which do not furnish instances, during every winter, of great storms, the destructive effect of which will justify their being classed under the head of phenomena.

As a rule, it will be found that the most violent gales come from the quarter where they have the greatest length of uninterrupted sea or direct line to blow over, at any rate this will generally be the direction in which the greatest waves will be generated. Thus, at St. Jean de Luz, at the southern extremity of the Bay of Biscay, the strongest wind is that from the N.W., in which direction no land is encountered short of Hudson's Bay, whilst at the south point of Bretagne, at the northern extremity of the Bay of Biscay, the strongest wind is that from the S.W., in which direction the first land struck would be the coast of Guayana in South America.

In the British Channel the prevailing wind is W.N.W.; but the winds by which ships riding in the Downs are most annoyed are from S.S.E. to S.S.W., which shews that the wind with the longest fetch is not invariably the most annoying. On the coast of Bretagne the prevailing wind is W. and S.; and in the Mediterranean it is a wind called the mistral, which blows from the W.N.W.

To guard against the effects likely to result from these successions of gales will of course be one of the principal considerations of the Engineer; but the attentive observation of the different directions from which the wind may affect the port is likewise necessary, with regard to the ingress and egress of the harbour. With an off-shore wind no consideration need be given to the safety of the mariner, inasmuch as his proximity to the shore will prevent his ever being assailed by very heavy seas; but it is, nevertheless, very advisable that he should be able to enter the port under sail, if possible, from whatever quarter the wind may blow, or, that when leaving it, he should not run the hazard of being embayed by the land to leeward.

V.—*Nature of Waves on the Coast.*

A wave may be generally described as an undulation or oscillation of the upper surface of water, caused by the action of the wind passing over it. We are speaking now of the ordinary waves of the ocean, as there are other causes of undulation, such as the tidal wave, caused by the attraction of the moon in its course round the earth; and there is also the earthquake wave, which never occurs but immediately subsequent to a convulsion of that nature. In the same way there may be undulations caused in the immediate vicinity of land by large land-slips, &c. Of the first of these (the tidal wave) we shall speak when we are treating the subject of tides; and against any other it is scarcely necessary that provision should be made, in laying out the plan of a marine work.

It is probable that, in the extreme depths of the ocean, perpetual quiescence reigns; probably nothing but the action of some of the great currents, such as the Gulf stream, ever disturbs its tranquillity. It is only at the surface, that the position of the particles of the fluid is altered, or its mass agitated, and the extent to which this takes place is dependent upon a variety of contingencies.

Waves partake of two characters, which have been termed by investigators of the subject "oscillation" and "translation." Waves of oscillation consist of little more than an undulation of the surface, accompanied by a slight disturbance of its component parts. In watching the progress of a wave, the observer is inclined to believe that the water is in rapid motion, but the distinction must be made between the motion of the wave, and the motion of the water. This difference may be easily distinguished by simply observing that the foam, which floats on the surface after the breaking of the crest of a wave, does not follow it, but continues to rise and fall in the same spot, a very slow progress only being caused by the direct action of the wind upon it.

The effect of undulation, without horizontal motion, may be observed on the surface of a field of standing corn over which the wind is sweeping. The heads of corn are successively depressed and elevated, forming unitedly an exact imitation of billows, but manifestly without quitting their position.

In deep water, the motion of the particles of water assumes a somewhat cycloidal motion, thus:—

That there is a certain progressive motion has been proved by Smeaton, who ascertained, by observation, that on a canal 4 miles in length the difference of level in a moderate breeze, by the gradual progress of the surface, was 8 inches.

M. Minard mentions a canal of 35 miles in length, on which a strong wind would produce a difference of level of the two ends of 6¼ inches. And it is to this gradual heaping up of the surface and readjustment of level, no doubt, that we may attribute many of those currents, of a most unusual kind, which occasionally beset the navigator, drifting him from his right course, and leading, not unfrequently, to disastrous results.

On the coast of Holland an on-shore gale will sometimes raise the surface several feet, and sailors assert that if they can only hold their anchors for a few hours, until the off-shore current commences, there is not much difficulty in saving themselves from going ashore afterwards.

Waves of Translation.—A wave of translation is a wave which, from some cause, has acquired a bodily horizontal motion added to its oscillatory one. It is from waves of this description that damage to marine works almost entirely proceeds, and it is therefore of great moment to ascertain how far theory or investigation has gone, up to the present time, in determining the nature of these waves, and the causes which produce them.

Mr. Thomas Stevenson states, that waves do not break or become entirely waves of translation until they reach water of a little more than their own depth, but that waves in a strong tideway break in deep water during calm weather. We have stated above, that waves of oscillation cause or are accompanied by a certain circular motion of the particles of water. To what depth this motion takes place is undetermined, but doubtless it has some ratio to the size of the wave; and it may be reasonably concluded that, so long as this motion has depth enough to develop itself, the wave continues a wave of oscillation, but that no sooner does the wave pass over a depth in which the motion is affected by friction on the bottom, than it commences to assume a new character and to become a wave of translation. The action of translation in a wave may be easily observed in close proximity to the shore. The waves being then retarded by their friction on the bottom whilst the surface retains the velocity which it has acquired from the action of the wind, the top overruns the inferior portion, and tumbles over and dashes itself on the beach. The velocity which it has thus obtained forces it up to a higher elevation than that of the natural surface, and it recoils, meeting in its descent the succeeding wave, which it is technically said to trip up, and which it deprives of a large portion of its force. The sea breaks on the north-east coast of England in at least five fathoms.

The Sunderland colliers cast out ballast at from 7 to 10 miles from the shore, and in violent storms this ballast is cast up on to the shore from a depth of eight fathoms. It may be presumed, however, that the transporting power of the waves on this coast generally ceases at 22 fathoms, as that is the depth at which mud scoured from the clay cliff is found. It has been ascertained that heavy ground swells break in 100 fathoms, and Sir Edward Belcher states, that, during his survey of the Eastern Archipelago, he ascertained that in typhoons and very violent tempests the agitation reached to a depth of 200 feet, and was sufficiently violent to break rocks to pieces at that depth.

Velocity and Length of Waves.—It is not easy to establish a basis from which the velocity of a wave may be ascertained experimentally, owing to the circumstance just mentioned of its not carrying anything along with it. Nor is it easy to find a position where a wave can be observed and timed between two objects, the distance between which is known. Mr. T. Stevenson, in his valuable work on the Design and Construction of Harbours, gives the following table from the observations of Mr. Douglas at the Bishop Rock:—

Height of Wave.	No. of Waves in a Mile.	Feet apart.	No. of Waves per Minute.
8	35	171	8
15	5 and 6	1,200 and 1,000	5
20	3	2,000	4

These measurements would give respectively, as the velocity with which the undulations travelled, about 1,368, 6,000, and 8,000 feet per minute. It may be supposed that these rates would be exceeded in the open sea. Mr. Stevenson likewise recounts some observations of the length of the waves, made by Mr. Mackintosh, the light-keeper at the Calf of Man, who states that on three different occasions he counted 13½ waves between the Calf of Man and the Chicken rocks, which would give 490 feet as the length of each wave. Dr. Scoresby gives 790 feet as the length of the Atlantic wave from crest to crest.

"Newton concluded that the velocity of waves formed on the surface of water, either by the wind, or by a stone thrown into it, was in the sub-duplicate ratio of their size. When their velocity of oscillation therefore is measured, the length of the waves will be determined by finding a pendulum which oscillates in the same time." Mr. La Grange states, that the velocity of waves in a canal is equal to that which a heavy body would acquire, by falling through a height equal to half the depth of the water in the canal, and that their velocity will vary in the sub-duplicate ratio of the depth, provided it is not very considerable.

Mr. Joshua Wilson dissents from this rule, and observes that "observation will show that it is the breadth of the expanse that determines the velocity." To prove this he cites "the great tidal wave which moves at a rate of some 500 miles an hour," but is "reduced to a tenth of that velocity in the narrow seas around this island."

However, calculations may apply to the motion of waves in the open seas, where the undulations are regular and unobstructed, but along a sea shore all the motions of waves must be more or less dependent on the features of the locality. There they have to meet with reaction from the shores, from the bottom, and from various obstacles which they encounter in their course, and it is consequently impossible to establish any theory by which their size or other characteristics may be estimated.

That the friction of the shore causes great diminution and retardation of the velocity, there can be no doubt. Every sculler on the river knows that the flood tide continues to ascend the centre of the stream for some time after it has ceased to flow near the bank. This may, in some measure, be accounted for by the increased momentum of the great body of water in the centre, but the friction near the shore is an aiding cause.

Besides waves of oscillation, and translation, there are waves of reflexion, and transmission, of which we shall have to speak when we are treating of the different qualities of harbours.

As regards the effects of waves on different coasts, Mr. T. Stevenson lays down the following characteristics:—

"1st. As the waves approach to parallelism with the shore line their destructive power is increased.

"2nd. Their power is increased in proportion as the direction of the main body of the tide approaches to coincidence with the direction of the heaviest swell, they are probably worst at those headlands on which the tide splits.

"3rd. At parts of the coast where strong tide currents set off the shore they reduce the waves by acting as a breakwater.

"4th. Where a considerable part of the coast retires, there will be less sea during the strength of the tide, even although the waves come in parallel to the shore, because the tide keeps outside, following the direction of the general *trend* of the coast. But this will probably not hold true of *small* re-entrant hollows of the shore.

"5th. Although the line of exposure and the tide-current are parallel to the coast, yet if the tide runs in a line very near to the shore, as is the case in short narrow channels where the velocity of the current is increased, there may nevertheless be a very heavy sea.

"6th. The most severely tried shores will be those where the line of maximum exposure is at right angles to the line of shore, and where it coincides with the direction of the principal tide-current."

The direction of the waves is generally that of the wind, but not always parallel to it.

Another point upon which much observation has taken place, but upon which perfect accuracy cannot well be attained, is the height of waves. Familiar discourse accustoms us to talk of *mountainous waves*, but it is a question whether any wave ever yet reached an altitude which would entitle it to be compared to a *hill*.

The height of the wave on the east coast might be taken at from 15 feet to 18 feet; and on the Dutch coast at from 6 feet to 12 feet.

Dr. Scoresby, who took much pains on many occasions to ascertain the fact, records the highest wave which he observed as not exceeding 43 feet, whilst the great rollers off the Cape of Good Hope are stated by Capt. Dayman to be 20 feet; and, perhaps, this may be fairly taken as the average deep sea wave, in a gale of wind, in the open ocean.

The height of waves is dependent not only on the direction and strength of the wind, and length of fetch, but also on the depth of the sea over which it has passed. This rule will hold good in all sheets of water. On the basin of the canal of Burgundy, which is of small extent, but which is from 30 to 70 feet in depth, the waves attain a height of from 6 to 9 feet; but in the lakes, where there is less depth, the waves seldom attain a greater height than 3 feet. In the Mediterranean the height of the waves seldom exceeds 15 feet, whilst in the Gulf of Gascony they will attain a height of 23 feet. (These figures refer to heavy gales; of tempests, which are only of rare occurrence, no measurement has been taken.) The waves are shorter in the Mediterranean than in the ocean. The shape of the bottom greatly influences the form and height of waves. The rock of Artha, in the Bay of Pascoyne, which has 30 feet water over it at low tide, has a marked influence on the waves which pass over it. Those peculiar rolling waves which are known under the name of "races," which occur off Portland, and between Alderney and Cape La Hogue, and in many other places, are due to unevenness of the bottom. Doubtless there are races which result from the meeting of strong currents under peculiar circumstances, but they usually occur in narrow straits, and are characterised by very broken water; whereas, we have passed over the race at Portland after a gale, when it has consisted merely of a number of large rolling billows, with scarcely a surge on the surface. There is a most extraordinary race in the Pentland Firth, between Scotland main land and the Orkney islands, which is doubtless caused by the extraordinary strong tide which runs there, meeting the swell of the ocean. This is apparent, from the fact, that the breakers are always most violent and dangerous at either end of the Firth, when the tide is setting out to sea. The same effect may be observed at the mouth of a river, when the current meets an on-shore swell.

VI.—*Tides.*

We shall not enter into the theory of the causes of the tides, further than to say that they are produced by the attraction which the moon and the sun exert on the water, covering a large portion of the surface of the globe. The solar flux and reflux of the tide is renewed by direct attraction, at every interval of a solar day; and in the same manner the flux and reflux produced by the attraction of the moon is renewed at

every interval of a lunar day. This tidal wave is raised directly by the attraction of the sun and moon, but there is also a second oscillation succeeding it, which forms the second tide in the 24 hours. As these two are formed, one by direct attraction, and the other by secondary action, it will be observed that at one portion of the year the morning, and in the other the evening tide, is usually the highest.

In estuaries and narrow channels, especially if their direction coincides with that of the tidal wave, a rapid current is formed which goes under the name of the tide, but this is not the case in the open ocean. There the tidal wave is simply an upheaving of the water to the extent of about 4 feet, and which follows the course of the heavenly bodies in an undulation at the rate of about 400 miles an hour. It is unaccompanied with any horizontal motion until the undulation is prevented, by a narrowing of the channel or other obstruction, from fully developing itself, when a contraction or compression of the tidal wave results which generates an onward horizontal motion. This motion is dependent, in its intensity, on the position of the channel, and hence the great variety of heights to which the tide rises at different places. The tide is augmented when the estuary is open in the direction of the tidal wave, especially if it be expanded towards its mouth; and *vice versâ*. Thus, in the Bay of Fundy, between Nova Scotia and New Brunswick, the tide rises to from 66 to 78 feet, whilst in the northern bay, on the other coast of the isthmus, which arrests the undulation, the tide only rises from 9 to 13 feet. Little or no effect is produced in land-locked waters. Thus, in the Mediterranean it varies from 6 inches to 3 feet, but scarcely anywhere exceeds 6 or 8 inches. The Caspian Sea has no tides. The Red Sea, from its peculiar form, has more the character of a river than a sea; and this circumstance, coupled with that of its direction, being open to the tidal wave from the Arabian Sea, makes it subject to very high tides, especially in its lower part.

The Baltic is wanting in regular tides, in common with all confined areas of water. In such cases, the moon must act equally upon all parts of its surface at the same time, and the oceanic tidal wave being obstructed by the sinuosities of the narrow channel, only penetrates a little way into the three passages which lead into that sea. The tide is also greatly reduced by promontories under certain circumstances. Thus at the S.E. point of Ireland, the greatest range is not more than 3 feet, while at a little distance along the coast each way it is 12 or 13 feet. The causes which have been mentioned above, as influencing tides, are here remarkably borne out, for the tides which prevail in the Bristol Channel, which is just opposite, are exceedingly high, amounting at Chepstow to 60 feet. These facts show to how great an extent tides are augmented by convergence; and that a contrary effect is produced by diffusion is shewn by the fact, that the tide, at the islands in the middle of the Pacific Ocean, is not more than 2 or 3 feet. But there is another peculiarity connected with the tides, which requires notice and explanation, namely, double or frequent recurring tides. Thus, in the upper part of the Firth of Forth there are sometimes as many as six tides a day; this is owing to the tide wave, which enters the German Ocean by the north coast of Scotland, not reaching the mouth of the Firth at the same time as the other portion of the tide wave, which passes down the North Sea and through the Straits of Dover. Smeaton in his report on Christchurch harbour says, "The great depth of this bay from the main channel tide, the shoalness of the waters occasioned by the sands, and the distraction of the current in going different ways round the Isle of Wight, I look upon to be the most probable cause of the smallness and irregularity of the tides here. It is not reckoned that the spring tides rise more than from 5 to 7 feet and the neap tides from 4 to 6; so that it sometimes happens that the neap tides are higher than the springs, depending much upon the course of winds. The tides are said to be highest with a S.E. wind, and least with a wind at N. I am also informed that, three hours after the regular time of high water, when the main tide in the channel begins to set towards the west, a second tide is formed in the bay, which is generally highest at neap tides, and that the ebb between the two tides is from 8 or 9 inches to 18; which second tide, proving a check to the reflowing power of the land waters, tends to weaken their force in getting to sea." The Port of Pool has a similar recurrence of tides, whilst some places have only one tide in the 24 hours.

The form of the mouths of rivers has a great influence on the height and time of high water. Thus, in the Adour, the embochure of which is funnel shaped, with its neck or narrow part towards the sea, the water remains higher on the outside than on the inside at high water, because the tide begins to fall before the river is full. This is detrimental to navigation, for vessels are detained in the river until the sea has descended to the same level as the water inside the embochure. The same effect is observed in the Tay, and the contrary at Chepstow. In fact, the conformation of every river will give it some peculiarity, in accordance with its form and direction. In all rivers running at an obtuse angle to the direction of the tidal wave, the tide water which ascends the river must alter its course and be detached, as it were, from the great tidal current. When the channel of the river is nearly uniform, the tide will gradually die away. "In the River Amazon the tide continues

to ascend for several days against the stream, and is still sensible at 200 leagues from the mouth. Seven or eight tides, with intermediate low water, follow in succession up this mighty river. Something similar takes place in the St. Lawrence. The tide reaches 432 miles up the main channel to a point between Montreal and Quebec;" and in the Bay of Fundy, the spring tide has been known to rise to the surprising height of 120 feet.

The velocity of the tide is altogether dependent on the character of the locality, as must be apparent from the fact previously stated, that in the open sea the tide is not accompanied by horizontal motion, which is only the result of the approach of the tidal wave to places where its development is interrupted or confined. In narrow straits it usually runs with increased velocity. In some spots it is scarcely perceived to move, whilst at others it assumes the character of a rapid. In the Pentland Firth, the spring tides have a velocity of 9 miles an hour. Off Cape La Hogue, the spring tides run 6 or 7 miles an hour.

Mr. T. Stevenson mentions an indication of the height to which the tide rises, which may be useful where means are not at hand to determine the question by inquiry or observation. It is the level of the lepas or barnacle. The highest level at which this shell fish grows is about high water of the highest neap tides or of the lowest springs. Grass or thrift he considers as a bad indicator of the height of the tide.

VII.—*Currents.*

Both mariners and Engineers should make themselves well acquainted with currents. Without this knowledge the mariner can never rightly estimate his position, because he cannot make a correct allowance for drift, and the stranding and wreck of his ship on approaching the land is the frequent result. The Engineer can, with as little confidence, determine the correct position in which to place his works, so that they may afford the greatest amount of succour to ships in distress, and facility of access and accommodation to those which seek them for purposes of commerce.

Currents vary greatly both in character and degree. Those, which most correctly come under the name, are the great main currents of the ocean, where, from some cause which has furnished matter for speculation and discussion to many of the wisest of mankind, vast extents of the ocean may be said to move themselves by some fixed law over large portions of the globe. There are great bodies of water moving independently of winds and tides, and sometimes contrary to both. Amongst the most extraordinary of these are the Gulf stream, and those great currents which are continually floating mountainous icebergs along the coast of North America, in spite of winds or even of the Gulf stream. Another great current is found flowing through Behring's Strait towards the north-east, and is probably connected with that from Baffin's Bay. On the coast of Africa, between Cape Verde and the Gulf of Guinea, a powerful current is experienced, flowing from west to east contrary to the general direction of currents, which is from east to west, or in an opposite direction to the earth's rotation. This current acts close to the coast and impels all vessels approaching it into the gulf. Other currents are produced or dependent upon those uniformly recurring winds, known in different parts of the world under the names of monsoons and trade winds. Such currents occur in the Straits of Sunda, between Java and Sumatra, where they set to the eastward again, contrary to the general motion. At Ceylon the current seems to follow the direction of the monsoon to southward and northward. In the Straits of Gibraltar a current is always entering the Mediterranean from west to east. Some currents are merely on the surface, whilst others are entirely beneath it, and can only be discovered by experiment.

Of these great ocean currents, it will not be necessary to say more in this treatise, inasmuch as they do not generally operate in the immediate vicinity of the land, and are not therefore calculated to greatly affect the works of the Engineer. There are some of them, however, which approach the land so nearly as to come in contact with it, either independently or by the influence which they exercise on the tidal current. When this is the case it must form part of those inquiries regarding the set of the tide, which can scarcely be observed and recorded by the Engineer with too much care. There are also many currents which, though dependent on the tide, must be distinctly specified, as they do not occur in the direction in which the tide wave moves, and are frequently contrary to it. These currents, from the very fact of their irregular course, will sometimes be found troublesome, and will require to be specially provided against. Between Cape La Hogue and Cherbourg the currents make nearly an entire circle in 12 hours, and vary greatly in rapidity. They are not affected by waves, but considerably by winds, which increase or diminish them according as they blow in the same or a contrary direction.

It has been already observed that after a continuance of strong on-shore winds, an under current will frequently set, in an opposite or off-shore direction. This current will have a strong tendency to carry the bed with it into deep water.

Every sudden projection or indentation of the bottom, or of the coast, will cause an eddy or a change in the direction of the current, the force of which will depend upon the rapidity of the current at the spot.

Thus on the coast of Poitou the flood tide runs nearly parallel to the coast. At St. Gilles a current detaches itself in a contrary direction to that of the principal one; and the same occurs at the sands of Olonne, further to the south. Now these effects are not produced by the action of the streams which empty themselves into those two ports, for at La Gachère, which lies between them, and where also a stream debouches, no similar effect is produced. But it will be observed that at St. Gilles and at Olonne there is a projection and subsequent receding of the coast, whilst at La Gachère there is neither the one nor the other. Solid jetties projecting from the shore produce the same effect. It will be therefore incumbent on the Engineer to consider what alteration of the set of the current is likely to be caused by any work of the kind which he may propose to construct; for the case may arise where the counter current may make it very difficult and perilous to run for the harbour; and although it may be said that this is the business of the captain of the vessel, still blame would be attached to the designer of any work by which such an effect was produced, if it could be shown that by a more careful arrangement of the works other results might have been secured. Owing to the reversal of the current by the piers of the Port of Havre, a vessel entering that port was frequently obliged to carry sail quite into the harbour, and an enlargement was consequently made in the outer harbour to enable vessels to check their speed before they reached the first flood gates. An inner harbour has since been constructed, by which vessels will be able to reduce the "way" on them by altering their course. Before this work was carried out mud banks were left, as at Ramsgate, on which vessels might run, without damage, in the event of their being compelled to enter the harbour with a press of sail, or from their having been compelled to slip their cables, and consequently entering without an anchor to let go, to bring them up.

BIRKENHEAD DOCKS.

LOW WATER BASIN.

PLATES Nos. 1 to 15, inclusive.

THE GREAT drawback hitherto felt, as operating very materially against the complete success of the Liverpool and Birkenhead dock system, is, that except at certain states of the tide, the docks are, practically speaking, closed against the entrance or egress of vessels of any considerable size. The half-tide docks on the Liverpool side of the river have obviated this difficulty to a certain degree, but still much inconvenience is occasioned by not having a dock accessible at all states of the tide,—an inconvenience which the fast increasing trade of the port has rendered serious. The low water basin is intended to supply that want, and it has been constructed so as to be freely used by steamers at the lowest point of low water. For this purpose a floating landing stage, something similar to those on the Liverpool side of the Mersey, is recessed along its southern wall. But the chief advantage connected with it is that it affords an entrance to the great float or dock. The great, and indeed the only difficulty that has been at all antagonistic to the success of this scheme is, that the silt, with which the waters of the Mersey are so largely impregnated, would begin to deposit itself when within the still water enclosure, and finally render the basin useless, by filling up that which has been excavated at such great cost. To prevent this, a system of gigantic sluices has been constructed, which, communicating with the great float, draw off thence sufficient water to scour the basin. Having thus given a brief account of the object for which the low water basin was designed, and the difficulty to be overcome in order to carry it out successfully, we will now proceed to a more detailed description of the basin and the works connected therewith.

It may be as well to mention, in starting, that the heights of the tides in the Mersey, as well as the levels of the several docks and entrances, are usually computed, for practical purposes, from a fixed point, known as the datum of the old dock sill, that is, the level of the sill of the entrance that formerly led from the river into the old dock. This sill was laid about the year 1716, when the old dock was built, and at the time when it was filled up the level was transferred to a tide gauge, which is preserved on the west side of the centre pier of the Canning Half-tide Dock, and is 8 feet 9 inches above the low water level of average spring tides.

The property of the trustees of the Birkenhead Docks and of the Birkenhead Dock Company was transferred to the Corporation of Liverpool in May 1855, confirmed by the Birkenhead Docks Act, 1855, and by the Mersey Docks Act, 1857, and afterwards vested in the Mersey Board in 1858. The Act for the construction of the low water basin, with the other works comprised in the Birkenhead dock scheme, was obtained in 1858 by the Mersey Docks and Har-

bour Board, and the works were commenced and carried on until the end of 1861 under the superintendence of the Engineer to the Board, Mr. John Bernard Hartley, and subsequently by the present Engineer, Mr. George Fosbery Lyster.

The low water basin is nothing more nor less than a long narrow creek, occupying the middle of the old estuary formerly known as Wallasey Pool. It extends in a westerly direction inwards from and at right angles to the river. Its length from the river margin is about 1,600 feet, with a width of 300 feet at the river entrance and of 400 feet at the end next the great float. It is excavated to a depth of 10 feet below the low water level of the lowest equinoctial spring tides. It is surrounded on three sides by strong and lofty walls of masonry. The water area is 14 acres. It is connected with the great float by a lock 240 feet in length by 50 feet in width. This lock is flanked on either side by the sluices which communicate with the great float (see Plate 1, No. 1).

The area of the great float is 112 acres, or about 542,000 square yards; which on spring tides may be filled to a level of 18 feet or more on the old dock sill, and run down for scouring purposes to 13 feet above the same level, thus running off in the space of 35 minutes (during which the sluicing operations would continue) about 40,000,000 cubic feet of water.

The Bradfield reservoir, the bursting of which caused such destruction of life and property, contained 912,000,000 gallons, a quantity which could be run from the great float, if the supply was sufficient, in a little over an hour and a half, with perfect safety to all concerned. The chambers which lead off this immense quantity of water consist of two tunnels, one on either side of the 50-feet lock, each 30 feet in width by 20 feet in depth. These are each terminated by a large subterranean dome-shaped compartment or chamber, from which branch off 10 sluices (see Plates 2 and 3), opening at 3 feet above the level of the bottom of the basin, and, but for the interval of the lock, stretch across its entire width.

The sluices (Plate 1) are 5 feet 2 inches in width by 8 feet in depth, and in the aggregate represent an area of 826 feet. The water is excluded from the chambers when not required for sluicing purposes by timber gates, similar to those made use of at ordinary dock entrances. The sluices are shut by ponderous cloughs or paddles of greenheart timber, fitted into smooth grooves formed in the masonry. Two sets are in place, one for the ordinary working of the system, the other for use when an examination of the inner set is required; provision is also made for a third set of wrought-iron rectangular paddles, to be used in case of emergency.

The main system is worked by means of hydraulic machinery supplied by Sir William Armstrong. The prime power for working is derived from the engines and accumulators placed in a large building adjoining the low water basin. This building is surmounted by a tower 201 feet in height, and forms a prominent object when seen from the river or the opposite shore.

Thus far we have confined ourselves to a general description of the basin and sluicing passages; we will now proceed to detail the particulars of their construction.

The entrance between the great float and the low water basin is 50 feet in width, and its extreme length from inner to outer caisson quoins is 320 feet; it is provided with three pairs of gates. The points of the sills are 8 feet 4 inches from centre of hollow quoins. The eastern sill, or that next the low water basin, is 25 feet wide, and laid at 12 feet below old dock sill; the adjoining platform is 29 feet wide, and laid at 14 feet 6 inches below old dock sill; the next sill, about the middle of the lock, is also 12 feet below old dock sill; but rises near the third sill to 9 feet below old dock sill; and the adjoining platform is laid at 11 feet 6 inches below old dock sill. The caisson sill near the float end is 25 feet wide, and is also laid at 9 feet below old dock sill. The whole of this passage is on bearing piles 4 feet 6 inches centre and centre, and the masonry, which is about 7 feet 6 inches thick under the sills, and 3 feet 6 inches thick under the platforms and chambers is laid on a bed of concrete 2 feet thick (See Plates 2 and 3). The side walls of this passage are 23 feet thick at the foundations, and laid about 19 feet below old dock sill, the coping being 26 feet above that datum. Some portions of this wall which receive the thrust of the gates are as much as 30 feet thick, and are carried to the coping at this thickness.

A sewer 4 feet × 6 feet is laid in each of these side walls at 14 feet 6 inches below old dock sill in the centre, and 13 feet 3 inches back from the coping. These sewers commence at the great float end at 11 feet 6 inches below old dock sill, and fall to 16 feet below old dock sill at the low water basin. The mouth of the sewer at the great float entrance is 8 feet × 5 feet 6 inches, and it branches off into a second sewer of 4 feet × 5 feet, terminating in cutwater openings for scouring the gate platforms. The cutwaters are 3 feet × 2 feet by 1 foot 6 inches deep, and the openings between about 5 feet wide. The groove for the caisson is 1 foot 6 inches wide, and abuts against the sill about 3 feet, having a bearing of 2 feet 3 inches against the side walls direct to the coping.

SLUICING CULVERTS.

The two sluicing passages are on either side of the 50 feet entrance, and the distance from the centre line

of the entrance to the centre line of the passages is about 115 feet. Each of these passages is provided with a single pair of timber gates, of ordinary construction.

The sills are laid at 8 feet below old dock sill, and are 16 feet in width; the point of the sill is 5 feet from centre of hollow quoins. The adjoining platforms are laid at 10 feet below old dock sill, and are 18 feet wide. The caisson sills are 26 feet wide, and laid at 8 feet below old dock sill. The passage widens out from 30 feet at the inside of this sill to 50 feet across at the caisson groove, so as to receive a 50-feet caisson. These passages are also laid upon bearing piles and concrete, in the same manner as the lock; and the masonry is 9 feet thick under the gate and caisson sills, and 7 feet thick under the platform.

At the commencement of the sluicing chamber the masonry is 6 feet thick, but inclines towards the low water basin end to 3 feet in thickness.

The sluicing culvert proper is 30 feet × 19 feet, with 13 feet of masonry on either side, and 4 feet above the crown.

The bottom of the culvert is an arc of a circle 64 feet radius; the sides are vertical for 7 feet 6 inches in height, when a sharp curve of 7 feet radius commences, and dies into the crown curve, the radius of which is the depth of the culvert, or 19 feet.

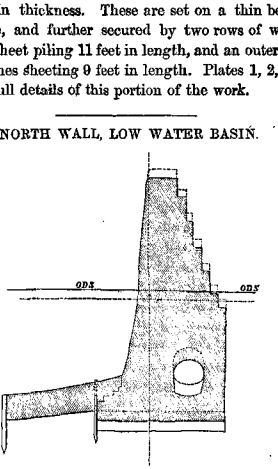
At about 75 feet from the east wall of the great float the sluicing passages are completely covered over. At this point the arching commences, and the culvert is 30 feet × 30 feet for a distance of 30 feet, when the crown is stepped down 11 feet, and then continues for a distance of 145 feet at its reduced section of 30 feet × 19 feet, where it terminates in a large dome-shaped compartment or air chamber, about 130 feet in length, 38 feet in width, and 38 feet in height, the arch being of two radii of 13 feet and 26 feet, and built in with 3 feet of solid masonry. From this chamber branch off the 10 sluice openings of 8 feet × 5 feet 2 inches in width, the granite piers between each opening being 9 feet wide. The middle pier is about 55 feet long, and each one gradually decreases till the shortest is about 45 feet. They are curved almost to a point at the chamber end, the radius of the curve being 16 feet. At the low water basin end they are also curved, but the end is square and 2 feet 6 inches in width, leaving the openings about 12 feet wide. An air shaft (6 feet diameter) and nine smaller ones are carried up from the crown of the dome to 10 feet above the coping level. An air shaft of 2 feet diameter is also carried up to the coping level in each of the other lengths of culvert.

Immediately adjoining the tower buildings are two large wells, each 16 feet × 15 feet, and laid at 27 feet below old dock sill; the sides represent an arc of a circle, the radius being 18 feet. A branch sewer of 4 feet 6 inches × 3 feet 6 inches runs from each of these wells, and joins a sewer 5 feet × 6 feet in the side wall of the passage, from which runs a small sewer of 2 feet 6 inches × 3 feet 6 inches, for the purpose of drying the chambers. Cast-iron cylinders 3 feet diameter convey the water from the chamber of the south sluice across and under the 50-feet lock, into the drying culvert just alluded to. The iron sewer commences in the south chamber at a level of 18 feet 3 inches below old dock sill, and falls to 20 feet 8 inches below that point, when it joins the drying culvert, which falls to 21 feet 2 inches below old dock sill; it then joins the large sewer, and falls further to 22 feet 7 inches below old dock sill, from which it runs into the wells. This small drying culvert leads to other portions of the work for similar purposes.

The side walls of the wells are about 7 feet in thickness, and have 12 inches close sheeting all round them at the foundations.

The bottom of the low water basin, in front of the sluices and lock, is paved for a width of 80 feet with heavy blocks of sandstone masonry from 3 feet to 4 feet in thickness. These are set on a thin bed of concrete, and further secured by two rows of whole timber sheet piling 11 feet in length, and an outer row of 6 inches sheeting 9 feet in length. Plates 1, 2, and 3 give full details of this portion of the work.

NORTH WALL, LOW WATER BASIN.



Scale, 20 ft. = 1 inch.

The north wall of the low water basin is straight, from the sluicing dam towards the river for a length of 1,450 feet, when it curves with a radius of 150 feet and joins the river wall leading towards the northern entrances. It is 51 feet in height and 27 feet 6 inches in thickness at the base, reduced by offsets to a thickness of 6 feet 6 inches at the coping level. The face is at a batter of 1 inch to the foot. It is constructed

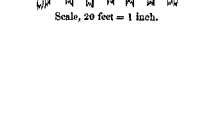
of squared sandstone set in random courses, but the circular return as well as the adjoining river wall is faced up with random irregular shaped granite, pick dressed. The level of the coping, which is of granite, is 26 feet above old dock sill. Bollards and pendant mooring chains are provided at intervals of 100 feet throughout its entire length.

The foundations for the straight portion of the wall are laid at a depth of 20 feet below old dock sill, and are on stiff dry clay, overlaid with a bed of concrete 2 feet 6 inches in thickness, from which the masonry is brought up at the back of the wall, and incorporated with it is constructed a sewer 6 feet × 7 feet, along its entire length. It commences in the north sluicing chamber, at the level of 16 feet 6 inches below old dock sill, and falls towards the mouth of the basin to 18 feet below old dock sill, where it expends itself through 11 culverts, constructed in the wing wall for scouring the sides of the fairway into the basin. This sewer stands 10 feet back from the face of the wall, and decreases in size to 6 feet × 4 feet in the wing wall, where it terminates in the scouring sewers, which are 3 feet × 4 feet 3 inches for running the water through the cutwaters. There are two cutwaters 4 feet × 2 feet 6 inches × 1 foot 6 inches deep, in front of each of the 11 cloughs, forming 33 openings 3 feet × 1 foot 6 inches deep, in face of the wing wall.

The coping is formed of large granite blocks, 3 feet wide by 7 feet from the edge, and laid about every 10 feet apart, the intervening coping stones being laid header and stretcher, and about 2 feet 6 inches deep, all these coping stones having a hold of 4 feet in the wall.

This wall having shown symptoms of weakness, it was found necessary to underpin it, by placing a toe of masonry, 5 feet in thickness, for a distance of 20 feet in front of the wall, with 6 inches and 12 inches close sheeting 13 feet in length on the outside of the toe.

SOUTH WALL, LOW WATER BASIN.



Scale, 20 feet = 1 inch.

The south wall of the low water basin is about 1,770 feet in length, and, at a distance of 1,600 feet from the south sluicing dam, curves with a radius of 200 feet and joins the river wall leading to the Morpeth basin. The wall is recessed 35 feet for a length of 1,030 feet to receive a landing stage; and about midway in the length of the stage, the wall is further recessed 15 feet, to receive the two landing-stage bridges. The face of the wall in these recesses is vertical. This wall is founded on bearing piles 4 feet 6 inches apart, 12 inches square, and driven over its entire surface with 12 inches close sheeting in front, and bins sheeting along the back. Between the piles is placed concrete 3 feet in thickness; the heads of the piles are cut off, and large blocks of ashlar are placed over every four piles; the building of the masonry commences at the level of 25 feet below old dock sill, or 28 feet to the bottom of the concrete. The masonry is 27 feet 6 inches thick at the foundations, and gradually decreases in thickness to 16 feet 3 inches at old dock sill, and then regularly steps back till it is only 6 feet 3 inches at the coping level, or 26 feet above old dock sill, making the entire depth of this wall 54 feet from coping to concrete foundation.

A sewer 6 feet × 7 feet is built in this wall, same as in the north wall, and extends from the south sluicing chamber to the river, and is used for the same purposes as the sewer in the north wall, a series of cloughs (twelve), with cutwater openings, being placed in the wing wall for scouring the basin. There are ten clough openings for scouring away any accumulations that may arise under the landing stage. This sewer commences at a level of 15 feet 6 inches below old dock sill, in the south sluicing chamber, and falls to 18 feet below old dock sill at the landing stage recesses, and continues at this level for the remainder of its length.

COFFER DAM, LOW WATER BASIN.

A coffer dam was erected across the entrance of the basin, in order to admit of the masonry and excavation work being carried out with safety and facility.

It was constructed in the form of a segment of a circle, the chord line being about 467 feet in length, and the versed sine about 76 feet. The dam was formed of timber piles driven close together in two rows, which were 23 feet 3 inches apart at the bottom; the outer row of piles had a batter of one-half inch per vertical foot, and the inner row a batter of 1 inch per vertical foot, so that, at their full height at the level of 26 feet above old dock sill, the two rows of piles were 16 feet 9 inches apart. The inner row of piles was driven down so that the foot reached 30 feet below old dock sill, the foot of the outer row being

driven down so as to reach 35 feet below the same datum.

The two rows of piles described were formed of whole timbers of Baltic pine, 14 inches deep crossway of the dam, and 12 inches wide longitudinally. From the level of the old dock sill, a lining of close-jointed 3-inch planking was nailed on the inside of each row of piles from end to end, and extended upwards to 25 feet above old dock sill.

There were five rows of walling timber on each side of the dam; each opposite row was fixed at the same level, and tied together with 2-inch iron rods at every fourth single pile, or about 16 feet apart.

The dam was supported upon the inside by shores and shore piles.

The construction of the dam was commenced in the centre, and carried each way from the centre simultaneously. Previous to any piles being driven, the site of the dam was excavated down to 10 feet below the old dock sill, and when a length of 100 feet of the close sheeting piling of both rows had been driven, the space between was excavated to 18 feet below old dock sill, the space so excavated being refilled with puddle.

The total length of the outer row of piling was 540 feet; the inner, 500 feet; and the number of piles, in both rows, was 1,040.

LOW WATER BASIN GATES—50-FEET ENTRANCE.

PLATE 15, No. 15.

The top of these gates is 26 feet above the old dock sill, the level of the bottom being 9 feet and 12 feet below that datum respectively, according to the levels of the sills. *The total height* of the heel post, from footstep to coping, is 36 feet 5½ inches. The height over "ribs," from bottom side of bottom rib to top side of top rib, is 34 feet 3 inches, and the length of each leaf, from outside of heel post to mitre, is 28 feet 11 inches. The gates are segmental in plan, having a versed sine of 8 feet 4 inches; they are composed of greenheart heel posts 20 inches diameter, greenheart mitre posts 17 inches and 16 inches. The two bottom and the top ribs are of greenheart, and the remaining ten ribs of Baltic pine.

The thirteen ribs in each leaf are distributed in the following manner, viz.:—The bottom cess is formed of four ribs, making a depth equal to 5 feet 4 inches of solid timber. Between the bottom and second cess is a space of 16 inches. The second cess is formed of two ribs, making a depth of 2 feet 8 inches solid. The second space is 2 feet, and the remaining ribs are placed singly at distances gradually enlarged to the top of the gates. The amount of solid timber occupies about seven-twelfths of the height of the gate.

The ribs are built in two pieces, each piece being the full length from heel to mitre post. The two pieces are jointed together, and bolted with six 1¼-inch screw bolts. The bolts used for fastening on the heel and mitre posts to the ribs are of 1⅜-inch round iron, except the top and bottom ribs, which are secured by 2-inch bolts. The bolts for securing the mitre post to the ribs are all of 1⅜-inch iron. The bottom cess is bolted together with six 1⅜-inch screw bolts having wrought-iron washers under head and nut. The second cess is bolted together with six 1¼-inch bolts with similar washers under head and nut. The "cesses" and ribs in these gates are strengthened by means of chocks of greenheart, placed in the spaces between them. The chocks are 8 inches thick, and of the width of the rib. There are three rows of these chocks in each leaf, placed at equal distances apart between the heel and head posts. On the front and back side of each leaf, and immediately opposite the above chocks, are placed back straps of greenheart 14 inches × 8 inches, running from the bottom to the top of the gate, secured by 1¼-inch screw bolts every sixteen inches through chocks and ribs, binding the whole together. The bottom spaces are planked with 3½-inch greenheart, and the remaining spaces are planked with 3-inch Baltic pine, well secured with galvanized iron spike nails, having a washer of tow and white lead under the head of each nail. The planking is rebated 4½ inches on and 3 inches down on the ribs. The whole of the seams or joints in the ribs and planking are caulked over with pitch. The head and heel posts are secured to the ribs, both back and front, with strong framing plates of iron 5 inches × ⅝ inch. The plates run from the bottom to the top of the gates, having arms on to each rib, 4 feet 9 inches long, let in level with the surface, and bolted together with 1⅜-inch clinch bolts at the heel, and screw bolts, 15 inches apart, at the head end.

Each leaf is strengthened by means of four fenders (of Baltic pine) on the front side, each 15 inches × 12 inches, cut to fit the front of the gate. These are secured by means of 1⅜-inch screw bolts, 2 feet apart, except at the ends, where ⅝-inch spike bolts, 12 inches long, are used.

At the top of the heel post is fixed a circular hoop of cast iron, having a flange running on to the top rib, secured by two bolts through the top ribs, and firmly wedged on to the heel post with wood wedges. This hoop is of 1½-inch metal, and weighs about 4 cwt. At the bottom end of the heel post is fixed a brass hoop of 1¼-inch metal, having in the centre a hollow boss for the pivot to work in. This hoop is also fixed on with wood wedges.

The recess in the hoop for the pivot and ball, on which the gate revolves, is 7½ inches diameter. This hoop weighs about 4 cwt.

The pivot, or centre, is of solid brass, 7 inches diameter and 14 inches long, one half of which, along with the steel ball of 4 inches diameter, works in the heel hoop, and the remaining half (excepting 1 inch for clearance) works in a cast-iron footstep, let into the masonry at the bottom of the hollow quoin. The hoop, at the bottom end of the mitre, is of 5 inches × 1 inch wrought iron, let in level with the timber on the mitre and front sides, and secured with wood wedges. The hoop, at the top end of the head, is of cast iron 6 inches × 1½ inches, having cross arms to strengthen it, and, on the mitre side, a series of right angled notches, for the purpose of inserting an iron bar to bring the gates properly to a mitre.

These gates work upon one set of cast-iron segments, at a radius of 24 feet from the centre of gate heel to centre of truck wheel. The segments are 20 inches wide at the bottom, and 5 inches thick in the centre, and 8⅓ inches wide on the top surface on which the wheel travels. They are bedded and secured to the masonry with 1½-inch screw lewised bolts about 5 feet apart.

The truck wheel is 2 feet 2 inches in diameter, and 8 inches thick, and works in a cast-iron frame upon brass steps. This frame is secured to the gate by means of wrought-iron staples, clipping the frame, and passing through the gate, the staple being 3½ inches by 1¾ inches. Into the truck frame is inserted a "spear" of greenheart, running the height of the gate, and, at the top of it, is a cast-iron abutment plate and pin, which is slotted to receive jibs and cotters for adjusting the heights.

The gates are opened and closed by a 1-inch chain, fixed to a staple at back and front; the chains then pass on friction rollers, in the side walls, to the crab boxes, which are placed as near as possible in a direct line with the pull of the chain.

In the lock walls, on either side of the gates, are fixed large cast-iron "chain boxes," each containing three rollers with brass pivots, acting as *fair leaders* to the crab boxes. These rollers are of cast iron, hollow, having a thickness of 1-inch metal, and work upon iron steps, and are covered with a cast-iron cap.

A gangway, or *bridge for foot passengers*, is fixed over the top of these gates, and is supported upon cast-iron saddles which clip and are bolted to the top ribs. Into these saddles is fixed a 5 inch × 3 inch wrought T-iron bearer, on the top of which are fixed 9-inch planks, bolted to the bearers with ½-inch bolts.

On each side of the gangway, wrought-iron stanchions and chains are fixed, for protection to the passengers. These stanchions are made on the front side to *ship and unship*, so as to be out of the way *when docking* or undocking vessels.

30-FEET GATES—SLUICING CHAMBERS—LOW WATER BASIN.

The constructive features of these gates are similar to the 50-feet gates, already described, for the entrance, except that the ribs are built in one piece, and the bottom cess of ribs being all of greenheart, as well as one rib in the middle of the height of the gate and the top rib; the remaining ribs are of Baltic pine. The heel and head are composed of solid greenheart. The alternate ribs and spaces in the height of the gate are as follows, viz.:—bottom cess solid, 5 feet 9 inches deep; first space, 1 foot 2 inches in depth; second cess, 3 feet 10 inches solid; second space, 1 foot 6 inches; third cess, 2 feet 10 inches solid; third space, 2 feet 3 inches; fourth cess, 2 feet 3 inches solid; fourth space, 2 feet 6 inches; fifth cess or twelfth rib, 1 foot 4 inches solid; fifth space, 3 feet ½ inch; sixth cess, or thirteenth rib, 1 foot 4 inches solid; sixth space, 4 feet; fourteenth, or top rib, 1 foot 4 inches solid: making a total height of 33 feet 1½ inches over the ribs. The height of the steel, from footstep to coping, is 34 feet 3 inches, and is 16 inches diameter in one solid piece. The head-post is 13 inches square, and also in one piece.

The width of each leaf, from back side of heel to mitre, is 17 feet 8¾ inches.

The bottom cess of ribs is 1 foot 7¼ inches broad in the centre, and the top rib is 1 foot 4½ inches, making the gate to taper 2¾ inches in its height. Chocks, backstraps, and fenders, as also the planking, are fixed in the same manner, and of similar timber to those of the 50-feet gates.

These gates revolve upon one set of segments, fixed at a radius of 13 feet 6 inches from centre of heel to centre of segment. The truck wheels, spears, staples, straps, anchor blocks, collar straps, chains, friction rollers, and crab boxes, are all fixed in a similar manner and composed of the same material, but of a lighter description than those of the 50-feet gates.

These gates are also segmental in plan, the versed sine being 5 feet.

BRIDGE, LOW WATER BASIN—50-FEET ENTRANCE.

PLATE 8, No. 8.

The bridge over the 50-feet entrance low water basin *is a swing bridge*, formed of three girders running its whole length, and supporting two intermediate roadways 12 feet in clear width, with a line of railway in each roadway, and footpaths 5 feet in width on either side of the outer girders. The bridge revolves upon a live curb of wheels, working upon tramways from a centre pin fixed in the masonry.

Its length is 115 feet 6 inches, and breadth 41 feet 3 inches. The centre, upon which the bridge revolves, is on the north side of the entrance, and is placed 26 feet 3 inches back from the coping line of entrance, the tail end of the bridge extending to 60 feet 6 inches back from the entrance, the nose of the bridge having a hold of 5 feet from the edge of the coping on the opposite side of the entrance.

The centre girder is 6 feet deep × 2 feet 8 inches wide, and the outer girders each 6 feet × 2 feet 2 inches, and are constructed upon the box principle, the top and bottom sections being made up of plates, angle iron, and bars riveted together. The joints of the bars butt well together, and are secured by means of accurately turned bolts. The girders are stayed inside by tee irons and diaphragm plates; sufficient space being left in each case for examination and painting.

The roadway between the main girders is supported by cross girders, composed of plates and angle irons; they are riveted to the main box girders about 4 feet apart. Strong cross girders are also placed between the main girders, directly above the rollers.

The rollers are 3 feet diameter, 26 in number, and are held in place by a circular wrought-iron framing 31 feet 6 inches diameter, and 9 inches deep, revolving upon a circular tramway 30 feet diameter; the bridge pit is 32 feet 6 inches diameter, and the floor of it is 5 feet below the coping of the entrance.

The transoms of the roadway are of American pine, 12 inches × 6 inches, and secured to the cross girders; but the pieces under the tramway are of greenheart, as also the planking, which is 9 inches × 3 inches. The outer curb and paneling is of pine, and the pieces, to which the standards are attached, are of English oak. The standards are placed every 4 feet apart on the outer side of each footway, with double guard rails for the protection of foot passengers.

The bridge is turned, by means of an hydraulic engine, the pipe for feeding which passes through the pivot and is fitted with a brass coupling joint pinion from the engine works into a cast-iron rack, which is also provided for turning the bridge by hand gear.

The pivot and socket upon which the bridge turns are made of cast iron, turned, bored, and accurately fitted; and the pivot is bored and recessed into the masonry.

A wrought-iron ballast box is placed at the tail end of the bridge, and heavily weighted with pig iron, &c. for the purpose of balancing, so as to secure its efficient working.

The bridge rails weigh 80 lbs. to the yard, and the bridge was proved with a gross load of one ton upon each lineal foot of roadway.

LOW WATER BASIN LANDING STAGE.

PLATE 13, No. 13.

On the south side of the basin is placed a tidal landing stage 1,040 feet in length, consisting of a substructure of wrought iron "pontoons" supporting four hollow beams or "kelsons" of wrought iron, on which rests a wooden deck, and the ends of two bridges leading to the quay. There are 46 pontoons of 33 feet 6 inches × 10 feet × 5 feet deep, and 19 of 48 feet 6 inches × 10 feet × 5 feet deep at one end, and 6 feet 6 inches at the other, fitted with water-tight bulkheads and angle and tee iron frames, and provided with pump and man-holes.

The kelsons are five in number (an extra kelson being placed between the bridges); four of them are of a uniform breadth of 3 feet across the top and bottom plates, and 2 feet from outside to outside of the side plates. The heights vary. The outside kelson next the basin is 4 feet 3 inches high in the middle, falling off to 3 feet 3 inches at the ends. The next or centre kelson of the stage is 4 feet 6 inches high in the middle, and 3 feet 6 inches at the ends. The inside kelson next the wall of the first recess is 4 feet 6 inches high for the whole of the length between the foot of the bridges, and 3 feet 3 inches high at the extreme ends of the stage; the fall is made to suit the incline of the deck. The fifth kelson next the wall in the inner recess is 2 feet 2 inches wide, and 4 feet 6 inches high between the bridges. Underneath the bridges the two inner kelsons are stepped down to 3 feet 6 inches in height, and then fall off with a regular curve to 2 feet 9 inches high at the ends.

There are ten cross kelsons placed between the third and fifth main kelsons of the stage. They are 3 feet across the top and bottom plates, and 2 feet from outside to outside of side plates. Two are 4 feet 6 inches high, and four 3 feet 6 inches; the remainder vary in height at the ends, from about 3 feet 3 inches, to 2 feet 9 inches.

The length of the deck of the stage is 1,038 feet over all, and the breadth 34 feet 9 inches for the greater part of its length, and 49 feet 9 inches for the remainder. The deck beams are laid 3 feet 2 inches centre and centre, 14 inches × 12 inches, notched out one inch, where they cross the kelsons. The beams are fastened to the flanges of the kelsons, where they cross, with 1¼-inch bolts let in flush; the upper surface is dressed only, the sides and bottom neatly dubbed. On the outside margin two longitudinal beams run the whole length of the stage (each 12 inches × 12 inches); the upper beam is bolted to the ends of the deck beams, and the lower one is fastened to the lugs provided for it on the kelson. The beams are in one

length only, across the width of the stage, with a camber according to the varying heights of the kelsons, and dressed to suit the curve and fall of the deck towards the ends. Upon these beams are laid the deck in two thicknesses: 1st, 4-inch planking running lengthways of the stage in 6-inch widths and 32-feet lengths, and fastened to the deck beams with square 9-inch ragged spikes; 2nd, 2-inch planking crossing the former, also in 6-inch widths, and in one length across the stage. The upper planking is fastened to the lower with square ragged spikes 5 inches long. Fender posts 12 inches × 12 inches are framed into the margin beams, and cast-iron bollards, 18 inches high, are fixed against every third deck beam along the outside of the stage, and the fender posts are suspended by 12-inch chains, shackles, and bolts; two chafing or rubbing pieces, the upper one composed of two 12-inch balks of English elm, and the lower one a single balk of English elm 15 inches × 12 inches, run along the whole length of the outside of the stage. Stanchions and guard-chains are placed along the river margin of the stage.

LANDING STAGE BRIDGES.

Plate 14, No. 14.

Two bridges connect the landing stage with the shore, and each consists of two parallel wrought-iron box girders supporting an intermediate roadway. Each girder is 152 feet 3 inches long, and 5 feet deep at each end, and 10 feet in the middle, the bottom having a camber of 6 inches, the ends rounded, and the top, the arc of a circle. The top of the girder consists of a square tube 26 inches wide × 18 inches deep, divided in two by a vertical partition in the middle, and the sides are 18 inches apart from outside to outside. The two girders are connected at the top by two arched stays, placed at equal distances apart. The roadway between the beams is supported by rolled iron joists 12 inches deep, with top and bottom flanges 5 inches wide, weighing 44 lbs. to the lineal foot, and placed 4 feet 6 inches centre and centre. The planking is in two thicknesses: first, 4-inch longitudinal planking of Baltic timber in 6-inch widths; second, 2-inch "Sabicu" timber in 6-inch widths, crossing the above for a width of 3 feet. In the middle of the roadway the hard-wood planking is 2½ inches thick, with chamfered edges.

The bridges are connected with the shore and allowed to run free on the stage, to admit of the vertical motion, occasioned by the rise and fall of the tide, and the means by which this is effected is as follows:—The shore end consists of three principal parts, viz., first, a heavy cast-iron bed-plate, having a pivot in the middle, fixed to the masonry on the quay; second, an axle of cast-iron working horizontally at the centre upon the pivot above mentioned, and, towards each extremity, turned to a cylindrical form; third, wrought-iron hooks or saddles, bolted to the under surface of the bridge beams, two under each beam, and hanging on the cylindrical part of the axle without any attachment to it. The stage end consists also of three principal parts; viz., first, a wrought-iron plate under each beam, riveted to the kelson with steeled face, forming a path for the rollers to run on; second, two wrought-iron turned rollers with steeled faces; third, wrought-iron hooks with brass journals bolted to the under side of the bridge beam, two under each beam, and bearing on the turned ends of the rollers. The openings of the joints are covered by a flap reaching from side to side of the bridge, and working on a hinge in the manner of a common butt hinge. It is of cast iron, with raised studs or footholds on its upper surface. The weight of the girders for one bridge is about 100 tons.

ACCUMULATORS.

Plate 7, No. 7.

The accumulator is a reservoir giving pressure by load instead of by elevation, and its use, like that of every provision of this kind, is to equalize the duty of the engine, in cases where the quantity of power to be supplied is subject to great and sudden fluctuations. The construction of the accumulator is shown on Plate 7, No. 7. It consists of a large cast-iron cylinder fitted with a plunger, from which a loaded weight is suspended to give pressure to the water injected by the engine. The load upon the plunger is usually such as to produce a pressure in the cylinder equal to a column of 1,500 feet head, and the cylinder is made sufficiently capacious to contain the largest quantity of water which can be drawn from it at once, by the simultaneous action of all the hydraulic machines connected with it. Whenever the engine pumps more water into the accumulator than passes to the hydraulic machines, the plunger rises, and makes room in the cylinder for the surplus; but when, on the other hand, the supply from the engine is less for the moment than the quantity used, the plunger with its load descends and makes up the deficiency out of store. The accumulator serves also as a regulator to the engine, for when the plunger rises to a certain height it begins to close the throttle valve in the steam pipe, so as gradually to reduce the speed of the engine, until the descent of the plunger again calls for an increased production of power.

STEAM ENGINE.

PLATE 12, No. 12.

The steam engine is arranged to work force pumps or chain pumps for drying the locks, hence the necessity of the reversing gear. The pipes are arranged to admit of either engine working by itself, either for force pumps or chain pumps.

The driving wheels on engine shafts for the chain pump gear are thrown in and out of gear by means of a simple ratchet motion attached to the shaft—the wheels sliding upon the shaft key.

FORCE PUMP.

PLATE 10, No. 10.

This is a modification of the bucket and plunger principle; the clack in the bucket is dispensed with and an external delivery valve (D) substituted. In this arrangement the out-stroke of the pump causes the water contained in the annular space surrounding the plunger (E) to be forced into the accumulator, while a further supply of water enters behind the piston through the suction valve (G); in the in-stroke the water behind the piston is discharged through the delivery valve (D), and half of it passes round into the annular space on the other side of the piston, while the remaining half is forced into the accumulator, the area of the plunger (E) being exactly half that of the piston (F). Each stroke of the pump thus delivers the same quantity of water into the accumulator. This principle gives equally easy access both to the suction and the delivery valves.

GATE MACHINES, &c.

PLATES 6 and 7, Nos. 6 and 7.

Plate 6, No. 6, is a general plan of the dock entrance, showing the lock-gate machinery. Instead of connecting hauling cylinders with each gate, as is very often done, a line of shafting (shown to an enlarged scale on Plate 7, No. 7), driven by a small water pressure engine, is laid beneath the surface of the ground, parallel with the coping, on each side of the entrance, and by means of clutches is thrown into or out of gear with each gate crab. A wire from the engine extends the whole length of the shafting, so that the motion of the engine can be governed from the point where the work is being done. The capstans are also so arranged as to be worked either by hand or thrown into gear with the shafting. (Plate 6, No. 6.)

The rapidity, with which the gates can be opened and closed by these appliances, is limited only by considerations of safety to the gates; and the operation is in practice usually performed in about two minutes.

HYDRAULIC ENGINE.

PLATE 10, No. 10.

The water pressure engines, most recently constructed for driving the shafting, consist of a combination of three oscillating cylinders, working cranks inclined at 120° to one another, with slide valves simply arranged. The cylinders are fitted with plungers instead of pistons, and are therefore only single acting. The slide valves are worked by the oscillation of the cylinders, communicated through the levers. When the back end of the cylinder is depressed, the slide valve is lowered, and allows the water to enter from the pressure pipe to the cylinder, where it acts upon the plunger in the out-stroke. In the return-stroke, the back end of the cylinder being raised, the cylinder port is closed to the pressure pipe and open to the exhaust. A small relief valve is provided in connexion with the cylinder pipe, opening against the pressure, which prevents any shock when the communication with the exhaust is closed, at the end of the return-stroke.

All the hydraulic engines about the locks are duplicates of each other. The gearing for working the engine valve is so arranged that a man standing at any one gate, machine, or capstan, can set the engine belonging to that particular series in motion. The gate machinery and capstans are arranged to be worked by hand in case of an accident to the engine.

SHUTTLES, &c.

PLATE 5, No. 5.

The shuttles for opening and closing the scouring sluices and levelling entrance are all worked by hydraulic pressure. They are raised or lowered by the direct application of a cylinder and piston fixed above the shuttle.

MACHINERY FOR BRIDGE.

PLATE 9, No. 9.

This is arranged to be worked either by hand or by hydraulic power. Handles are placed on centre girder of bridge, commanding the clutch gear to either the hand power or hydraulic power arrangement. Handles for turning gear and communicating with the hydraulic engine which is placed underneath the bridge, are also fixed to centre girder. Plate 10 gives full details.

CHARING CROSS STATION ROOF.

PLATES 16, 17, and 18.

THIS ROOF is 512 feet in length. The clear span between the walls is 164 feet. The principals are placed 35 feet apart centre and centre. The height of the top of the rib from springing is 45 feet, and rise of the tie bar at the centre of the span is 25 feet. The principals are fourteen in number, besides the gable principal next the river, and are, with that exception, alike. The gable principal differs entirely in construction from the other principals. The rib is considerably strengthened, the tie is horizontal, and is composed of a trussed girder. The space between the rib and the horizontal tie is filled in with wrought-iron uprights, strongly trussed, to which are attached wooden frames to carry the glass, with which the greater part of the external face of the gable principal is covered. The ordinary principals need no description, as the drawings speak for themselves. The purlins extend from principal to principal, and are therefore nearly 35 feet long. They are lattice girders, 1 foot 8 inches deep; they rest on the lower flange of the rib of the principal, and are attached to the principal securely at top and bottom by bolts with slotted holes. The rib being only 1 foot 6 inches deep, and the purlins 1 foot 8 inches deep, they project above the top of the rib 2 inches. To the purlins is attached the covering of the roof, which consists of glass and zinc. The glass is carried by wrought-iron sash bars, composed of T-iron, which are riveted to the purlins. The zinc is carried by 1½-inch boarding attached to the purlins. Two tiers of wrought-iron trussed frames are introduced between each principal. They extend parallel to the principal from the walls to the eighth purlin. Their use is to support the purlins laterally, and tie them all firmly together. On the top of the ribs, two purlins are fixed, of a different construction. They are girders of plate iron, 18 feet 2½ inches apart, and rest on the upper surface of the rib of the principal. The wrought-iron sash bars are fixed to the upper surface of these purlins, and, by this means, additional slope is given to the glass. On the top of these purlins are fixed cast-iron standards, to support louvres for purposes of ventilation. The space between these purlins is covered with a small wrought-iron roof, covered with boarding and zinc.

Means are introduced at one end of each principal for counteracting the effects of expansion and contraction, for the details of which the reader is referred to the drawing.

No wind ties, in the ordinary acceptation of the word, are used in this roof. The purlins being all bound together in the way described, by means of the riveted sash bars and the bracing frames; the whole roof is united in so firm a manner that the highest winds produce no injurious effect. Mr. Hawkshaw is the Engineer to the Charing Cross Railway Company, and the roof was constructed and erected by Messrs. Cochrane & Co., of Dudley.

GREAT NORTHERN RAILWAY.

DIGSWELL VIADUCT.

PLATE 19.

THIS VIADUCT, which is one of the largest works on the Great Northern Railway, was designed by Joseph Cubitt, Esq., Member of Institution of Civil Engineers, Engineer to the Company. It consists of 40 arches, each 30 feet span, is 1,563 feet long, and 100 feet high from the stream to the level of the rails. It is built of kiln-burnt bricks, the whole, excepting the abutments, being carried up in cement. In consequence of the peculiar nature of the ground in the lower part of the valley, 11 piers (Nos. 7 to 17 inclusive, from the south end) were timbered. The foundation of each of these is formed by 65 piles, 12 inches square, which were driven by a steam pile-engine, with an 18-cwt. monkey, until they would not sink ⅛ inch with a blow of 20 feet fall. They were then cross-braced and planked, as shown by drawings.

The novelty in the construction consists in the piers and abutments being cellular, bonded at intervals with Yorkshire paving, having four courses of

brickwork on each bond. The arches are turned with four rings throughout, the extra thickness for increase of strength being four additional rings, forming back ribs, bonded to the main arch, as shewn on enlarged section.

The piers batter 1 in 30 on the ends, and 1 in 40 on the sides. The imposts, string course, and coping are of Warden stone.

The quantities are as follows:—

Timber in 11 foundations	19,844 cubic feet.
Wrought iron in pile shoes and bond	26,387 lbs.
Excavation in foundations	17,957 cubic yards.
Brickwork in mortar	4,485 „
„ cement	31,338 „
Masonry	45,662 cubic feet.
6-inch iron water pipe	1,874 feet.

Cost, £69,397, or £133 4*s.* per lineal yard.

GREAT NORTHERN RAILWAY.

ROBBERY WOOD VIADUCT.

PLATE 20.

THIS VIADUCT, erected from the designs of Joseph Cubitt, Esq., Mem. Inst. C.E., is about 23 miles distant from King's Cross Station. It carries the Great Northern Railway over a dip near Robbery Wood, north of the Welwyn tunnel, and about a mile north of the Welwyn station. It consists of seven arches, of 22 feet span, is 27 feet 8 inches between the parapets, and 56 feet from the road to the level of the rails.

The piers and abutments are of solid brickwork, as shown by the drawing. The bricks are kiln burnt, and the mortar is composed of stone lime and sand. The imposts, string course, and coping are of dressed Portland stone.

The quantities are as follows:—

Excavation for foundations	900 cubic yards.
Brickwork in piers, abutments, and parapets, mortar	2,497 „ „
Do. in arches, spandrils, &c., in cement	656 „ „
Portland stone in imposts, string course, and coping	2,096 cubic feet.

Cost, £4,643, or £70 7*s.* per lineal yard.

METALLIC AND MINERAL PERMANENT WAY.

PLATE 20A.

IN TIMES gone by, timber sleepers were destroyed chemically, *i.e.*, by rotting under alternate moisture and dryness. That was in the days of small engines and light trains, while the influence of the Liverpool and Manchester prescription, one ton load per wheel, was still operative. That load has grown now to a minimum of two tons, and a maximum of seven tons, and cast-iron foot plates are deemed a wise arrangement for procuring the adhesion of engine wheels by iron ballast. Chemical destruction, by rotting, is therefore no longer a vital question, as mechanical destruction, by blows, has superseded by its rapidity the longer process of rotting, at least on main lines in England, and in the hard rain and hot sun of India, and similar climates; and even there the timber rots faster in the ground than out of it; and if timber is to continue in use it is evident that it is not well adapted for sleepers or foundations, but only for superstructure. Upon the whole, wood is out of favour, and railway engineers say, "Give us an elastic metal way, and we will dispense with timber altogether."

The undesirability of putting timber sleepers in direct contact with ballast was perceived very early. George Stephenson did not consider it *Permanent* Way, and so took to stone blocks, the defects in which we have described, and criticised, in a former number. To remedy this, Mr. John Day, in the beginning of the year 1835, devised in cast iron a kind of skeleton sleeper, in two halves, bolted together, and clipping the rail between them, the sleepers being on short lengths, discontinuous, with vertical walls and a flat base 15 inches wide and 30 inches long, the base being 18 inches in depth from the surface of the rail. The difficulty of getting access to this base to pack it was as bad as with the stone blocks, and there was another disadvantage, inasmuch as it was necessary to disturb the seating

of the sleeper, on the ballast, in order to shift a rail; the amount of cast iron was very considerable, and it appears that the weight and depth was depended on to maintain the gauge, as there was no framing or tie bars to keep the two opposite rails in relative position. This arrangement was applied to the narrow gauge.

About the same time Mr. Reynolds, on the broad gauge, endeavoured to produce an efficient permanent sleeper, by casing a longitudinal wood sleeper in continuous lengths of cast iron. This sleeper (Fig. 1), from its peculiar form, was christened the "hog-trough" sleeper. It formed a wedge in the ground or ballast, at an angle of 45°, with the ends flanged to bolt the lengths together. The rail, timber, and sleeper, were all bolted together vertically to outside lugs. Thus the longitudinal timber formed the bearing for the rail, and the cast iron was interposed to give a more extended bearing, the timber being supposed to furnish elastic action. But the timber was not truly elastic, that is to say, it had no resilient flexure. It was compressed below the rail in the cast iron, and the cast iron broke in pieces at the connexions. A worse structural form could not well have been devised. It was a sharp wedge, continually driving into the ballast, under the pressure of the wheels, and always getting loose. This also went into the category of negative experiments, demonstrating another process that would not answer.

About the same period, Mr. Greaves produced a hollow cast-iron sleeper (Fig. 2), at first a pyramidal form, and subsequently a bowl inverted, generally known as the "pot sleepers." This was to a certain extent an imitation of the stone block, inasmuch as it was made solid by filling with ballast. But it had an advantage, in being provided with openings at top, through which ballast could be rammed and packed, without the need of digging up the surface ballast, to get access, and so leaving a loose bed to absorb rain. Like most new plans variations had to be made; the first tie rods were merely connexions and not framings. When the Egyptian line was in hand timber sleepers were considered impracticable, and there was no ballast,—only alluvial soil. One objection to these sleepers was their tendency to roll on their concave interior, the sharp edges of the bowl cutting into the ground and tilting the rails irregularly, and moreover the thinness of the metal at first adopted rendered the bowls liable to split. Charles Heard Wild in adapting them for Egypt, considerably increased the thickness, and framed the tie with the edges vertically through the bowls, firmly keying them in; thus forming a kind of cross sleeper.

An advantage in these sleepers is their hemispherical form, which keys them into the ground, and thus holds the rails down. A disadvantage is, that, in common with all chairs, there is a very small bearing surface for the rail, with a wood key of insufficient size, subject to get loose. And the chair heads cast on the bowls give an objectionable form for packing in transit. But notwithstanding, this was at the time, the only available system of iron way, and its introduction in Egypt, led to its introduction in India, and so to a very extended use, from the habit of imitation. The defects were gradually amended, by the upgrowth of a class of men, who grew accustomed to them. Perceptive faculties are not common, and an existing contrivance, to which we are accustomed, is generally regarded with more favour, than a perfect system which we do not instinctively understand. The type set is apt to continue the type in use. "Carpenter, I want you to make our hog a new hencoop," said the farmer's wife, who on first squatting had put the little pig amongst the chickens, and continued the practice from habit ever after.

The next cast sleeper was by Mr. Peter Barlow, of which he had two varieties. One was a hollow trough base (Fig. 3) with chair heads cast on it fastened in the usual manner by wood keys, two chairs on each sleeper. A worse form to insure steadiness could not well be imagined. It was 10½ inches high to the top of the rail, and only 14 inches wide, the base perched as it were on a potatoe ridge. It was strong enough, but the base was simply a longitudinal extension of Greaves' section.

The other variety was a sleeper (Fig. 4) with a flat base, and a longitudinal rib below, two chair heads above for the intermediates, and three for the joints. But the sleepers were in two halves with half jaws of the chairs on each, and bolted together with bolts beneath the rails. The height of the rail above the bearing surface on the ballast was only 8 inches to a 14-inch base, and the base being flat was altogether much steadier. But the great length of the sleepers, and their thinness, and the small bearing at the chairs instead of extending over the whole length caused great brittleness and breakage. To obtain durability they would have required at least double the weight of metal which was used. But the form was bad, and far more efficient sleepers could have been made with the same amount of metal.

The next cast-iron sleeper (Fig. 5) was by Mr. De Bergue, showing much ingenuity of detail. It was a flat base of iron very thin, with a cross network of cellular ribs and edges on the surface like a honeycomb, giving great strength with great lightness. But great care was required in annealing, to ease the strains on the metal, in cooling down after casting. A single headed rail was clipped under the metal projection on one flange, and bolted down on the other with an eye-bolt, also receiving a vertical tie bar, *i.e.*, edgewise, making a stiff framing to the two opposite sleepers; the area was an oblong, lengthwise with the

rail. Breakage occasionally took place from imperfect annealing, and subsequently the ribs were diminished in number, and increased in thickness; there was a rib below to give lateral hold in the ballast. One advantage was the weight given by the ballast filling the cells; another, the flat bearing. A disadvantage was liability to break without very careful packing; another disadvantage was want of grip in the ballast. The bearing surface area was equal to a 9-inch width throughout, under each rail, the sleepers being each 18 inches in width and spaced apart. The bearing of the rail on the sleeper was on two narrow ribs 10 inches apart.

The failure in Mr. Barlow's sleepers gave for some time a lull to cast iron, and wrought iron became the favourite. So far back as 1845, Mr. Buck produced a wrought-iron sleeper, an inverted trough of thin wrought iron, with iron straps to keep it from spreading. But it appears not to have been successful. The rails were fixed to it by chairs bolted down by key bolts. In 1849 Mr. William Barlow produced his saddle-back rail (Fig. 7), formed to furnish its own bearing in the ballast, dispensing with sleepers altogether, whether of timber, stone, or metal.

Great results were expected from this rail, and it came largely into use. Its apparent cheapness and strength, and its simplicity in the model form, attracted great notice, and many lines were laid with it. But it was full of fallacies, and was a failure, as subsequently acknowledged by the producer, in full conclave of the profession. The reasons why it ought to fail and did fail were apparent to those who looked beneath the surface. We will recapitulate them.

An efficient rail should possess both vertical and horizontal stiffness, to resist flexure by the load. The bridge rail of the Great Western is defective vertically, but very strong horizontally. The Barlow saddle back is merely a bridge rail altered in form and with an extended base. If the two sides were vertical and the base horizontal, it would be a bridge rail. But in a futile attempt to increase vertical strength, the two sides are placed at a curved angle, and thus, when the load comes on, the rail tends to spread out, and the head tends to crack longitudinally when worn. And when the rail is fixed to timber sleepers, to prevent it from spreading, it splits longitudinally, along the hollow curve. And it is unfitted for curved lines, from difficulty of bending laterally. And, moreover, no efficient joint could be applied. The saddles which fitted under the two rail ends were only fixed at the edges by rivets, like two thicknesses of boiler plate, the only strength of which was, as a tension bar, as long as the rail ends abutted together at the top. If they did not abut, the edges bent down and left the joint with a deep hollow top. If they did abut, there was no room for expansion, and a hot sun twisted the line like a snake. Neither could they be used in efficient ballast, needing soft ashes or sand. And the bearing surface only extended about four inches on each edge of the rail where it was flattened, the hollow above crushing down the ballast in form of a potatoe ridge.

The next wrought-iron way was that of Mr. W. Bridges Adams, Fig. 8. It was a compound system. A double-headed rail, 7 inches in depth, the wearing tables $2\frac{1}{4}$ inches wide by $1\frac{3}{4}$ deep, and the vertical web less than half an inch in thickness. The bearing surface in the ballast was formed by two angle irons bolted through the side channels of the rails, in which they fitted top and bottom, being slightly curved to give an elastic action in screwing up the bolts, and so produce a tight fit. The total width of bearing area on the ballast was $13\frac{1}{4}$ inches, and the lengths of angle iron were made to break joint with the rails, and also with each other. The two opposite rails were connected together by edge vertical tie bars cranked at the ends to take the bolts of the angle bearing plates at any interval required. The bolts were all below the bearers when *in situ*, and for convenience in putting together they were laid bottom upwards, and joined together in lengths of $\frac{1}{4}$ mile. They were turned over by applying a lever at one end, and thus a twist was produced which gradually went from one end to the other like a long snake. A portion thus laid was connected by the tie bars, forming a frame lying on the ballast, with the lower table only, bearing over the surface, and with the breaks of the pits from which the sleepers had been taken out intervening. While so resting, with no bearing but the rail tables, $2\frac{1}{4}$-inch, equal to 5 inches in width the two rails, trains passed frequently over it, and the only effect produced was sinking into the ballast about $\frac{1}{4}$ inch, showing how very small a bearing surface is really required if the rails be stiff and unyielding, so as to distribute the load and prevent crushing in detail.

This rail laid equally well on blowing sand or dirty ballast and on flint nodules. The sand was gradually compressed into a block of sandstone beneath the horizontal webs, and clinging round the bolt heads and nuts, and lifting with them in blocks when the rail was raised. The horizontal webs were laid on dry material and covering in the sand at top, they shut out the entrance of rain water, save at such an angle as passed far below the rail.

It will be seen that the long angle bearers, fitting closely the rail channels, which had very little bevel top and bottom, dispensed altogether with fishes and fish bolts, the depth being $3\frac{1}{2}$ inches instead of the ordinary $2\frac{3}{4}$ inch fishes, this and the square fit, against the shoulders, gave to the joint nearly twice the strength of ordinary fishes, and by experiment, it was found that the fish bolts always gave way at the ex-

treme pressure; the angle plate bolts never gave way at all, even when the angle plates were bent to a considerable vertical angle. Moreover, in no instance were the bolts found to get loose in the ground under work.

There was no blow whatever in running over this line, but there was the peculiar ring between metal and metal in contact, induced by the sledging action common to all railway wheels. One remarkable result was obtained. It was not possible to alter its normal form laterally by the running of the trains. Being inaccurately made in the first sample, frequent attempts were made by the platelayers to straighten it by what is technically called "slewing," *i.e.*, moving it laterally and packing it tight, as is done by cross sleepers. But pack it ever so well, with the first train over it, it returned to its normal form, and the attempt had to be given up. This, which "practical men" regarded as a defect was, in truth, a demonstration of efficiency. With accurate manufacture it would have been impracticable for engine lurches to have disturbed its form.

The disadvantages of this arrangement were, 1st, the difficulty of bending the rail round sharp curves; 2nd, the difficulty of getting access to the bolts, which might, however, be an advantage in semi-civilized countries, as being less liable to be stolen; 3rd, the complete system of break-joint adopted, which rendered needful the removal of many pieces and bolts, in order to remove or change a rail; and, lastly, the extreme solidity of the rail tables, which precluded elastic resilience, and caused more rapid wear. And, in common with all longitudinal way, it needed special arrangements for draining below the rails.

The advantages were its extreme steadiness *in situ*, the rail being only elevated 2½ inches above a bearing base of 13¼ inches, and a keel 4½ inches below, to keep its lateral position, and sufficient depth to maintain a level top.

Another variety of this continuous wrought-iron permanent way, in illustration of the same principle, was produced by what is called a T-iron section. It was a flat plate 12 inches broad, with a keel 4 inches deep, running along the centre below, giving lateral hold in the ballast; on this was bolted down by vertical bolts a bridge rail or foot rail, called by the French a mushroom head. The disadvantage of this was want of vertical stiffness, the rail and bearer being laminæ, each bending under the pressure of the wheels, and throwing great strain on the bolts, which frequently broke, making it needful to put strips of timber between them; but this was only palliating the evil, crushing the timber in detail instead of tearing off the heads and nuts of the bolts.

Subsequently to these, Mr. Macdonnel produced another variety of wrought-iron rail (Fig. 9); it was a curved base of sheet iron forming an inverted trough like the Barlow rail, but with the edges turned down instead of being horizontal, so that the bearing surface was in the middle instead of at the edges. The object of curving the edges was to obtain vertical stiffness. On the top were rolled three ribs, one to pass into the hollow of the rail and the other two to confine the edges. Between the rail and bearer were laid strips of wood, the whole confined by vertical bolts.

This was an inefficient structure; the edges acted like a plough-share on the ballast with the side lurches of the engine and train. They gave comparatively little vertical strength, and the only strength at the joint was the horizontal web of the rail and that of the bearer, making altogether an inch in thickness. In fact, the joint had to depend for support on the packing of the ballast. It was subsequently found necessary to bolt deep T-irons beneath the joints, to support them; but even then they had to depend on the lengthening tension of the vertical bolts to keep the joint together.

Subsequently to this, another variety of permanent way was produced in wrought iron, by Mr. Spencer (Fig. 10). A foot rail was bolted down on a continuous length of corrugated iron plates, the corrugations running transversely to the rails. Transversely, it was very stiff, but longitudinally it had no stiffness whatever, and as the rail was shallow it depended wholly on the ballast to maintain a straight top. The rails were fish-jointed in the ordinary way. Like the Barlow system, it was fastened together by rivets, but with rivets greatly multiplied, and the first sample laid down did not induce its extension. It was a system rendering it very difficult to replace a rail. This was the last of the continuous bearing system that we are aware of.

The objection to the continuous bearing of a rail on sleepers or base, is, that if the rail be vertically shallow, it depends on the base for support. If that support be of timber it sinks in, in detail. If of metal or stone, it gets hammered out, and destroyed by the blows of the wheels. If again, the rail be stiff enough vertically, and have no elastic action below it, its own rigidity will cause it to be destroyed, and to obtain true elasticity, unless we suppose it bedded on a continuous length of vulcanized rubber, is impracticable without a discontinuous support. In vulcanized rubber, thinness of material is essential to durability, but it is too costly and too treacherous to be available for a railway.

Subsequently to these trials, Mr. Burleigh produced a system of iron permanent way (Fig. 11). Dispensing with the wood sleeper, each chair was extended into a sleeper some 18 inches square, with a

slight upward convex, and a shallow ribbed edge below, to stiffen it on the four sides. On the plan, it was made wedge form, so that the two opposite sleepers might dovetail into a straight iron tie bar, forcibly driven on to them. For a rigid way, and not too great speed, this might answer very fairly, but there was no elasticity, and the defects, consequent on this, were of the usual kind. It had one desirable quality in permanent way where it can be managed —it had no screw bolts.

One important thing in permanent way, if cast iron be used for sleepers, is to distribute the bearing of the rail over a long surface. Cast-iron sleepers may thus be made in short lengths, and may be placed as close together as will permit the convenient bending of the rail round curves. The diagram annexed, Fig. 12, gives a simple mode of accomplishing this. The rail is single headed, with a thick edge below to prevent cracking under tension. A sleeper 2 feet long, and channel form, giving a keel below, and a pair of horizontal wings, receives the rail, which is suspended by the upper table on two rising longitudinal ribs on the whole length of the sleeper. To keep it in position, a round iron key, pointed at the end, is driven through sleeper and rail, the holes being respectively arranged to draw rail and sleeper into forcible contact. Each pair of sleepers is connected by an angle iron tie bar with a flat web below, and the other web vertical, held in vertical position by a bolt of round iron bent into a parallel form, so that the web of the angle is held between; the angle iron tie bar is quite straight, and the curbings are so made as to give a pitch to the rail. This form of sleeper, owing to its great depth, is very strong, and at the same time not heavy, and the bearing area is six times the length of the ordinary chair. It will be seen that the general form of the section resembles the wrought-iron way of Mr. W. Bridges Adams, and has therefore the same steadiness in the ballast. And by this arrangement fishes and fish-bolts are dispensed with, for the sleepers being 2 feet long, and giving a full length bearing to the rail, is better supported than by the fish, which is usually 18 inches in length, and has moreover a nearly square bearing instead of an obtuse angle. Four keys, driven through the sleeper and rail, two to each rail end, thus form a better fastening than the ordinary fish-bolts, with the fit at an angle of anything but repose, in fact depending wholly on the end strength and power of the bolts. Although this system is deficient in elasticity, it is perfectly free from all separation or "knock" between the rail and sleeper, and will be far more durable than the cross sleeper system, with the rails jumping up and down in the chairs, as the keys work loose with the grinding of the rails. This system is used for a railway in Trinidad, and gives great satisfaction, having very few parts and all closely fitted, but here no very great speed is attained.

But this system gives only a single-headed rail, and though a single-headed rail dispensing with chairs and not reversible may be thought economical in the United States, a double-headed rail may be more economical where the means of re-rolling are not at hand. And though a double-headed rail, badly fixed in chairs and subject to both tables being battered in work, may not be desirable, it may be so with the sleeper, before described, in which the rails, being suspended, are not subject to the same amount of injury.

Therefore in this second example, a sleeper (Fig. 13) is shown adapted to a double-headed rail. It is suspended by the head on the inner side, and on the outer side by a rolled distance piece, through which the transverse key of round iron passes and holds it in its place. As the rail is suspended, only a very thin web is needed, and a 65-lb. rail will be found more available than a 75 on the ordinary plan, and no fishes or bolts are needed.

Still there is no elasticity, and every sleeper, though held firmly to the rail, is, like other cast-iron sleepers, a kind of anvil, if the wheels produce blows, as every chair is an anvil when its weight is great. The true system is that of elastic resilience as illustrated by the elastic timber system in a former chapter. But timber is ill fitted for the tropics or hot climates generally, and the question becomes imperative—how to make an iron way elastic; not elastic in the sense of playing up and down, but with that amount of elasticity which will prevent all destruction, which will prevent iron rails from being destroyed by blows and crushing, and make them at least as durable as steel rails are, under the present conditions. That such a result has been practically obtained with wheel tires, renders it certain that it may be done with rails, between which and the tires, action and reaction are equal. If, therefore, elasticity be provided in the wheels at the point of contact with the rails, a very rigid road may be available, or *vice versâ*, an elastic roadway will prevent destruction from rigid wheels. The mischievous effect produced on cast-iron sleepers is illustrated in the 36th Report of the East Indian Railway Company for October 1864, wherein the Engineer, alluding to the cast-iron pot sleepers, says,—

With large ballast the cast-iron pot sleepers

cracked and broken per cent.		per annum	20
Small ditto	ditto	ditto	21½
Mixed ditto	ditto	ditto	25½

"It is found that when one sleeper is changed the two on either side are very liable to break, so that in this way the cost of both labour and material will be still further increased."

In short, to prevent cast iron from breaking, it is essential greatly to increase the strength and weight of material, adding to freight as well as other cost. And when strong enough not to break, the rails will begin to suffer in greater proportion, unless the wheels be provided with resilient action. If cast iron is to be used, so as not to damage wheels or rails, or suffer breakage, it must be by the interposition of an elastic medium.

The plan, Fig. 14, shows a similar sleeper to Fig. 13, in cast iron, but the rail is not suspended by the upper table. Instead of that, it rests upon a plate of spring steel disposed in the bottom of the sleeper channel so as to give elastic action. The limit of play is very small, but so arranged that no blow whatever can take place in the process. The rail is keyed down tightly on the springs by round iron keys on the inside before described, but supported at the sides by cast-iron distance pieces between the rail web and the sleeper jaws, through which the round key passes to retain the rail in position. Taper fishes and bolts are used between the sleepers, which are kept as close to the fish ends as possible. And these fishes are tapered in length, giving great strength at the joints and keeping the bolts elastically tight.

It is obvious that in these three samples the sleepers may be kept nearly close together, making an almost continuous bearing, but without interfering with curvilinear construction. Practically it is not needed to keep them so close. Spacing them at 3 feet apart, the distance of ordinary cross sleepers, will leave intervals of 1 foot between, which will serve well for drainage.

The width of the sleepers, Fig. 12, is 12 inches, and the bearing area per mile about 7,040 feet super.

Fig. 12.—The quantities of material in a single mile are as follows:—

	lbs.	Tons. cwts.
504 rails, 21 feet long	40 per yard	62 18
3,520 cast sleepers, 2 feet long	63 each	99 0
5,032 round iron keys	0¾ „	1 14
1,760 tie bars, 4 feet 8½ inches long	14 „	11 0
3,520 hook head bolts	1 „	1 12
Total weight		176 4

Fig. 13.—Bearing area per mile, 7,640 feet super. Quantities of material in a single mile.

	lbs.	Tons. cwts.
504 rails, 21 feet long	65 per yard	102 3
3,520 cast sleepers, 2 feet long	70 each	110 0
5,032 round iron keys	0¾ „	1 14
3,016 cast-iron distance pieces, internal, 6 inches long	3 „	4 1
504 joint do.	16 „	2 5
1,760 tie bars, 4 feet 8½ inches long	14 „	11 0
3,520 hook head bolts	1 „	1 12
Total weight		232 15

Fig. 14.—Bearing area per mile, 6,625 feet super. Elastic Way.—Quantities of material in a single mile.

	lbs.	Tons. cwts.
504 rails, 21 feet long	65 per yard	102 3
3,018 cast sleepers, 2 feet long	75 each	101 1
3,018 round iron keys	0¾ „	1 0
504 pairs fishes	22 per pair	4 19
2,016 fish bolts	1 each	0 18
1,509 tie bars, 4 feet 6 inches long	14 „	9 8
3,018 hook head bolts	1 „	1 12
3,018 tempered steel springs, 12 in. × ⅜ in. × 3 in.		5 8
6,036 iron distance pieces	2 „	6 16
Total weight		233 5

These sleepers, with springs in them for the rail to rest on, are spaced at intervals of 3 feet 6 inches, for the advantage of the elasticity is more than equivalent to the reduction of bearing area on the ballast. Bearing area needs increasing in proportion to the blows of the wheels. If there be no blows, as with elastic bars and rails, the sleepers will sleep and not rock. The bearings are also at the bottom of the sleepers, instead of above, as in Figs. 12 and 13.

But there are cases in which it is possible to combine timber with metal. In cold climates or in temperate climates, if timber be kept out of contact with the ground, there is no reason why it should not be durable. In this case timber may form elastic longitudinals, and metal or stone may serve for the sleepers, which may then be fixed in a perfectly rigid manner. When the cost is not too great, or the work is hard and incessant, the most durable plan would be to lay down stone paving, covering the whole road and dispensing with porous ballast, as the rain would be prevented from entering, and there would be no need to provide for its exit, any more than in the streets of towns. On the paving the longitudinals should be laid, bolted down at intervals of three feet on shallow blocks of hard wood, leaving a hollow space between of 1½ inch. Upon the longitudinals, the rails should be attached by chairs or brackets spaced at 3 feet or more over the hollows. On this system no wood cross sleepers would be needed, and there would be no sand or ballast to damage the machinery. For brick viaducts, such a system would be well adapted, keeping the arches dry, and preventing the outward thrust of the parapet walls. And, what is more important still, the elastic action would prevent much noise and the disintegration of the brick work. The amount of saving in maintenance of way by this system would be something considerable.

Supposing stone paving to involve a difficulty, iron sleepers may be applied with advantage. Short inverted troughs of cast iron (Fig. 15), connected with tie bars will bury firmly into the ground, and the

packing may be endwise at the level without opening out. On these solid packed sleepers may be fastened the timber longitudinals, as described in a former chapter. The sleepers, with the load distributed by the longitudinals, would remain firm fixtures, and the longitudinals would be out of the ground. The longitudinals, bolted between rubs in the sleepers, are capable of adjustment to the gauge without disturbing the sleepers in the ballast. This is a very important consideration in maintenance of way, for it is desirable never to disturb the sleepers when once firmly bedded. The conditions thus provided for are, durable sleepers, the load of the wheel always distributed over two or more and never on a single sleeper, an elastic medium between the wheels and sleepers, and the timber out of the ground.

Fig. 15. Bearing area, per mile, 7,350. Quantities of material in a single mile.

	lbs.	Tons. cwts.
504 rails, 21 ft. long - - -	70 per yard -	110 0
3,520 cast sleepers, 2 ft. 6 in. -	75 each -	117 18
3,520 chairs - - - - -	22 „ -	34 11
3,520 chair clips - - - -	2½ „ -	3 18
3,520 hook head bolts - - -	1½ „ -	2 7
1,760 tie bars - - - - -	14 „ -	11 0
564 pairs fishes, 1 ft. 6 in. - -	22 pair -	4 19
2,016 fish bolts - - - -	1 each -	0 18
	Total weight -	285 11

Add timber longitudinals :—
1,174 9 feet × 5 inches × 10 inches.
3,520 wood keys.

The quantities are large, but it would be *permanent* way, and probably the saving in maintenance would soon repay the outlay; there would be no need of opening up, to pack the sleepers or to soften the ballast.

An experiment, on the North London Railway with a short length of elastic line, shows that a bearing area of cross sleepers placed 6 feet apart is amply sufficient when they are bolted to longitudinals, and no blow takes place directly on to the sleepers.

Fig. 16 is an illustration of Mr. De Bergue's new system.

Fig. 17 represents Griffin's "Economic" system, which is being extensively used on the Great Northern and London and South-western Railways. The advantages claimed for it by the inventor are its simplicity, safety, and cheapness. The quantities are as follows :—

	Length.	Weight.	Tons.	cwt.	qrs.	lbs.
502 rails -	21 feet.	82 lbs.	129	0	0	0
2,515 sleepers -	2′ 7″ × 1′ 6″	100 „	112	5	2	4
1,006 tie bars -	—	15 „	6	14	2	26
2,515 wedges -	—	6 „	6	14	2	26

Giving a bearing surface, for a 21-foot rail, of 2795·5 square inches, equal to a continuous longitudinal bearing of 11·1 inch in width.

But it is possible to substitute with advantage wrought-iron sleepers for cast iron, and so to obtain a material not to be broken, and at the same time yielding a certain amount of elasticity to save the rails from damage. Experiments are now making with this arrangement, which we shall be enabled to give in a future number. It will be very important to be enabled to save one-half of the dead weight in freight for exportation to the Colonies.

We shall next deal with the question of what is commonly called "Rolling Stock" and its damaging property to the rails by sledging action and blows.

MERTHYR, TREDEGAR, AND ABERGAVENNY RAILWAY.

CLYDACH VIADUCT.

PLATE 21.

THIS VIADUCT is from the design of John Gardner, Esq., C.E., and carries the above railway over the Clydach valley. It is constructed for a single line of rails, on a curve of 10 chains radius, and a gradient of 1 in 38. It consists of 8 semi-circular arches, each of 30 feet span, is 312 feet long, 13 feet between the parapets, and 75 feet from the stream to the level of the rails.

It is built of old red sandstone, the mortar being composed of Aberthaw lime and *forge ashes*. The rubble masonry, whether in face work, or as backing or hearting, consists of large, hard, and flat-bedded stones, no stone being less than 6 inches in thickness, nor less than 12 inches on the bed at the narrowest part. The whole is laid in horizontal beds, well squared on the points, neatly snecked, and picked smooth on the face. At intervals of 12, 15, and 18 inches in height, as best suits the stone, the work is uniformly levelled, and then well grouted. Through bond stones are set in the work in every superficial yard, measuring on the face of the work. Where the walls are not more than 3 feet 6 inches thick, the bond is in one stone, 3 feet 6 inches long, passing through to back and front. Where, however, the walls are of

greater thickness, the bond is made in two courses, the lower course consisting of two stones, set end to end, so as to pass through the wall; and the upper course, of one stone, set upon the other two, so as to break joint. There are 3,254 cubic yards of this rubble masonry, which, at 17*s.* per cubic yard, amounts to £2,765 18*s.*, or £26 12*s.* per lineal yard.

N.B. The above does not include the cost of wing walls or concrete in foundation.

MERTHYR, TREDEGAR, AND ABERGAVENNY RAILWAY.

VIADUCT OVER THE RIVER EBBW.

PLATE 22.

THIS VIADUCT was designed by John Garduer, Esq., C.E., and is constructed for a double line of railway. It consists of seven semi-circular arches, each of 30 feet span, is 271 feet long, 26 feet between the parapets, and 67 feet from the river to the level of the rails.

It is built of blue limestone, with mortar composed of Aberthaw lime and forge ashes; the rubble masonry being precisely similar to that of the Clydach viaduct, already described. It contains 3,814 cubic feet of stone, the total cost being £3,814, or £42 7*s.* 7*d.* per lineal yard.

Fig. 1 is an elevation, Fig. 2 is a section through pier, showing spandril walls.

CORNWALL RAILWAY.

COLLEGE WOOD VIADUCT.

PLATE 23.

THIS VIADUCT is situated at Penryn, on the Falmouth Extension of the Cornwall Railway. It consists of 15 openings of 60 feet clear span, is 964 feet long, and 105 feet in height, and is a type of numerous others on the same railway adopted by the late Mr. Brunel. The piers are of snecked masonry, and the superstructure is of timber, while the abutments are merely planked platforms resting upon the embankments.

The struts are framed and so arranged that, in case of repair, any one of them can be taken out without injury to the stability of the structure, and can be replaced in a very short space of time, so that the passage of trains need not be interfered with.

The iron bracing is distributed so as to prevent one part of the structure lifting when the strain is between the two preceding or two following piers.

The quantities are as follows:—

Granite masonry, including quoins,	5,112 cubic yards.
Excavation in foundations	2,180 „
Granite ashlar blocks on top of piers,	834 cubic feet.
Yellow pine, kyanized	22,005 „
Oak, in wedges and butt pieces	360 „
Wrought iron	841 cwts.
Cast iron	396 „

The cost of which was £11,130, or £34 10*s.* per lineal yard.

DUBLIN WINTER PALACE.

PLATES 24, 25, and 26.

THIS BUILDING is erected within the city of Dublin, and will be opened in May 1865, as an International Exhibition of Arts and Manufactures. It will afterwards be converted into a place of amusement, with lecture and concert halls, winter garden, and part of it as a permanent exhibition.

The palace may be said to consist of two distinct portions, as shewn by Fig. 4, Plate 24, viz., that built of brick and stone, and containing concert room, refreshment rooms, &c.; and that built of iron, intended partly for winter garden, and partly for permanent exhibition.

The general dimensions and outline of construction are shewn by Figs. 1 and 4, Plate 24. The span of the main roof, from centre to centre of columns, is 50 feet 6 inches, and the widths of the galleries are 16 feet 10 inches and 33 feet 8 inches.

The columns and girders are of cast iron; the main roof ribs are of wrought iron; the gallery floors are of timber, with wrought-iron truss rods; while the enclosure is of wood frames and glass, the plinths under the windows being of corrugated galvanized iron.

The Winter Garden portion of the building, viz., that 84 feet wide, is covered with glass in wooden skylight bars, the purlins (see Fig. 1, Plate 26) being of cast iron, and the openings in them glazed.

The "Permanent Exhibition" portion of the building, or that 117 feet 10 inches wide, is partly covered with zinc laid on wood rolls, and partly with glass; the side enclosure of this part being principally of corrugated galvanized iron.

The chief novelty of construction consists in the means adopted for resisting the thrust of the main roof, the depth of which at the centre is only 1 foot 6 inches, making it practically an arch requiring abutments. In similar cases, vertical diagonal bracing has been applied; as, for instance, at the International Exhibition of 1862, and also at the large conservatory in the Horticultural Gardens, at Kensington.

This method of bracing, however, was considered objectionable, and the engineers in this case devised certain arrangements, which have proved very successful, and are, at the same time, economical. Commencing at the springing of the main roof ribs, the transverse section (Fig. 1, Plate 24) and the half elevation (Fig. 1, Plate 25) show cast-iron open-work buttresses, carried down to the arched roof girders over the galleries. These arched girders, which are cast in two pieces, and firmly connected at the centre, are attached to the columns with bolts at the upper part, and by wrought-iron keys at the springing, the scantlings and various connexions being accurately calculated to resist the strain from the main roof ribs.

Below the gallery floors are open transverse girders, cast with strong brackets at each end, the latter being intended to reduce the leverage on the columns, as is the case with the arched form of the roof girders. They are firmly bolted to the columns.

In order to complete the abutment, the bases of the two corresponding columns are bolted to a girder, which forms the bed-plate (as shown in Fig. 1, Plate 24), and is laid on rubble piers underneath the columns.

The gallery floors are trussed in a novel manner; for, instead of the trussed beams being supported by the girders, thus causing *them* to transmit the load to the columns, the truss rods are carried diagonally and directly to the columns. By this arrangement that amount of metal is saved which would be required in the girders for transmitting the load to the columns; and also a horizontal bracing is given to the structure.

Mr. A. G. Jones, of Dublin, is the architect, Messrs. Ordish and Le Feuvre, of London, the engineers, and Messrs. Beardwood and Son, of Dublin, were the general contractors, and Messrs. Rankin Brothers, of Liverpool, supplied and erected the whole of the ironwork.

LONDON, CHATHAM, AND DOVER RAILWAY BRIDGE OVER THE THAMES AT BLACKFRIARS.

Engineers.—Mr. J. Cubitt; Mr. F. T. Turner.
Resident Engineer.—Mr. W. H. Thomas.
Contractors.—Messrs. Peto and Betts.

Plates Nos. 27, 28, 29, 30, and 31.

This bridge forms part of the Metropolitan Extension of the London, Chatham, and Dover Railway, the Act for which received the Royal assent in 1860. In the following year, 1861, the Corporation of the City of London determined to rebuild Blackfriars Bridge, and selected from the designs submitted to them, one for a new bridge of five arches of the following spans, viz.: the two side arches 155 feet each, the two intermediate ones 175 feet each, and the centre arch 185 feet.

The dimensions of the new road bridge, having been thus settled, fixed, at the same time, those of the railway bridge; its proximity to the former rendering it

highly desirable to make both bridges of the same spans, or at all events to keep the piers in the same line, so as to interfere with the waterway under the bridges as little as possible.

The foundation stone was laid on the 2nd May 1863, and the bridge was opened for traffic on 21st December 1864.

The total length of the bridge is 995 feet, and its width 55 feet, four lines of rails being laid down. The bridge is carried at a uniform level of 32½ feet above Trinity high-water mark (see Plate 27, No. 1).

The two shore abutments were built in ordinary pile coffer dams, that on the Middlesex side being a half tide dam only. The abutments are constructed of brickwork and concrete, and are carried down to the London clay at a depth of 27 feet below Trinity high-water mark, and built up nine feet in thickness to the level of low-water mark, from which point the stonework is carried up. The permanent way of the bridge being carried by three lattice girders, each so called pier consists of three distinct structures or piers, which are built quite separate and independent of each other, one for each girder.

The piers are formed by three wrought-iron cylinders 18 feet diameter, sunk in through the mud and gravel until they reached the clay; the water was then pumped out and the clay excavated from the cylinder, until it had reached the required depth. The excavation was then carried down to a depth of five feet below the bottom of the cylinder, and the base widened out to 23 feet diameter, in the case of the centre cylinder, and 21 feet in that of the outside ones, and the space filled with concrete. On the top of this, hardened bricks in cement are laid up to within four feet below low-water mark, at which point the masonry is commenced and carried up to six feet above high water mark.

After being laid, the blocks of stone were fastened together with brass cramps, and dove-tailed in, like the keystones of an arch, so as in strength to be equal to a single block of 18 feet diameter and 4 feet thick (see Plate 27, No. 1). The temporary iron caissons, which reached from about 2 feet below low water to about 6 feet above high-water mark, were then removed, and the groups of iron columns erected.

Each group consists of four massive cast-iron columns, which, united, have a total diameter of 14 feet. These spring from ornamented pediments, and are joined together at the top by a capital about 4 feet high, making the total height of the columns from the masonry about 26 feet. The columns are in single castings, 5 feet external diameter, cast perfectly true and of an even thickness, nowhere less than 1¼-inch metal for those supporting the side girders, and 1½-inch metal for those under the centre girders (see Plate 31, No. 5). The interior of the columns and the central spaces are filled solid, with the hardest bricks procurable, set in equal portions of clean river sand and Portland cement. The top of the brickwork is set with an incline to the extreme points up and down the river, so as to carry off the rain water through the cast-iron gurgoyles, 3 inches in diameter, which are fixed in the capitals of each group of columns. Each group carries two wrought-iron cross girders, on which are placed the packing blocks at the fixed ends of the main girders, and the rollers at the ends where the expansion and contraction is provided for (see Plate 31, No. 5). The whole of the brickwork is rendered in cement, and the wrought-iron girder, interior of capitals, and brickwork are covered with 1 inch of asphalte, laid on in two coats of half an inch each.

The longitudinal girders, carrying the superstructure, are wrought-iron lattice. They are 16 feet deep, but the centre one is made of extra strength, having double duty to perform. The lattice bars are made to resist tension and compression alternately. The tension bars are merely strips of flat-bar iron, but the struts, to resist compression, are of channel iron, each pair being braced together with strong stays, to prevent them buckling (see Plate 30, No. 4).

The arrangement of the plates in the top and bottom flanges, and the sectional area of the girders at different points, are shewn in Plate 29, No. 3.

Every part of the iron work which is exposed to the action of the atmosphere has been so placed, as to be easily painted by the most ordinary hand labour, while the troughs of the girders have been thickly lined with asphalte, so that the slightest chance of rust is carefully guarded against. Where the spans of the main girders join over the groups of columns, their junctions are concealed by massive ornamental castings. In the same style, the termination of the girders at each end of the bridge is ornamented also with massive castings. The cross girders are of wrought-iron plate; the bottom flange is curved (fish belly), which gives a depth of 1 foot 9 inches in the centre, and less than 1 foot at the ends, where they are riveted to the main girders. The top and bottom flanges are double angle iron, 3½ inches × 3½ inches × ½ inch, with cover plates 8 inches × ¼ inch; the web is $\frac{5}{16}$-inch boiler plate (see Plate 28, No. 2). The cross stays from girder to girder are of curved lattice-work. There are three to each span, and are bolted to the top flanges of the main girders. The wrought iron, whether bar or channel iron, is of the very best description, and was specified to be able to sustain a tensile strain equal to 18 tons per square inch of section. The struts, which are of channel iron, were required to be subjected to a compressive strain of 10 tons per inch. For the remaining details, we must refer our readers to the Plates, which will be

found to contain every detail of consequence, connected with the works. The bridge was fully opened for traffic on the 21st December 1864, before which it was tested by the Government Inspectors, and proved to be strong enough to bear, without danger, the greatest strain that can possibly come upon it.

Unlike the railway bridge at Victoria, where economy was studied at the expense of effect, or that at Hungerford, where the exigencies of railway traffic had to be reconciled to the architecture of a light suspension bridge, Blackfriars enjoys the advantage of having been designed for its work from the outset, and no one can look at its massive group of columns, and the bold yet light superstructure, without feeling that the design is a successful one. There are few, however, when the new Blackfriars (Road) Bridge is finished, who will not regret the unlucky fatality, which placed these two structures just so far apart as to prevent their being united in one, and just so close together as to hide the beauties of each.

We have refrained from giving an account of sinking the cylinders, as we believe a paper is in course of preparation, and will be read before the Members of the Institution of Civil Engineers, after which we shall give a full description in a subsequent volume of the Record.

LONDON, CHATHAM, AND DOVER RAILWAY.

THAMES BRIDGE.

PLATE 32.

SPECIFICATION FOR WROUGHT-IRON CAISSONS.

THE WROUGHT-iron caissons for the piers will be 12 in number, to be put down, six in work at once, thus requiring six sets of the upper or temporary part.

The depth, to which the caissons must be sunk, is 55 feet below Trinity high water; this depth applies to all piers irrespective of the present bed of the river. The permanent portion of the caissons is to be filled solid with the hardest stock bricks, set in Portland cement. At the level of the top of permanent caisson, the masonry pier will commence, which will be carried up inside the temporary portion, to such height as may be found convenient before letting in the water.

The greatest care must be taken in setting and sinking the caissons, to set them perfectly correct as regards position, and to keep them vertical whilst sinking. No attempt to pump out the water must be made, until the solid clay has been penetrated to a depth not less than 5 feet, and so as to guard against "a blow" taking place.

The caissons must be made and maintained perfectly watertight, and no water must on any account be admitted, when the foundations are approaching their ultimate depth.

The caissons must be made of best Staffordshire iron, capable of sustaining a tensile strain of 20 tons per inch; and the whole of the workmanship must be as for the best quality of boiler work.

The greatest care will be requisite in making each separate part of the caisson perfectly true and out of winding, on the end surfaces, which must be planed true, and be made perfectly circular, the bolt holes being all drilled to one template. The joints between the lengths will be made watertight, by means of a vulcanized india-rubber ring $\frac{3}{4}$-inch in diameter, or other approved means, and such accuracy will be required in the workmanship, that any one portion will fit any other portion, without straining or alteration. (The manufacturer's attention is particularly drawn to this very essential point.)

The joint, between the permanent and temporary portions, will be made with red lead and herds, soft wood wedges being used if required. The parts are held in place by 12 long bolts, $1\frac{1}{2}$ inches diameter, so constructed that they can be removed after the masonry has been carried up a considerable height; this must be attended to in fitting the eyes in place.

The stays, or stiffening rings, will be riveted to the outer skin, and must be made of a true circular form and of the dimensions shewn on the plans.

Four straps and rings must be attached to each separate portion, as shewn on the drawing, for the purpose of hoisting and lowering; and an orifice or waterway 8 inches in diameter, for inlet and outlet of water, must be made in the lower part of each length of caisson, and fitted with a slide cock of the same diameter, conveniently fixed for opening and closing.

Three temporary lengths of additional rings to be provided; these are to be used in case of any extraordinary high tide; they will be of plates 2 feet 6 inches $\times$ $\frac{1}{4}$ inch wide, 3 inch $\times$ 3 inch $\times$ $\frac{1}{4}$ inch angle iron.

The rivets throughout are to be of the size and

pitch mentioned on the drawing, and of the best quality of rivet iron.

They are to be put in red hot from head to point, and to be well hammered up so as perfectly to fill the rivet holes, which are to be punched true and fair, and accurately corresponding in the parts riveted together, and should any holes not fulfil these conditions they must be carefully rymered out.

ALBERT HARBOUR, GREENOCK.

PLATES 33, 34, 35, and 36.

THE RAPIDLY increasing trade of Greenock having for a long time demanded further accommodation for the shipping connected with that port, new works were projected, and under the direction of Mr. John Thomson, C.E., as Resident Engineer, have been successfully carried out, on an entirely new principle, herein-after described.

The Albert Harbour is situated on the west side of the town; and the outer pier, when carried to the full extent proposed by the Engineers-in-chief (Messrs. R. B. Bell and D. Miller), will be upwards of 3,000 feet in length. As yet, however, only one half of this has been constructed, leaving the prosecution of the remainder till some future time.

In consequence of the great expense that must have been incurred, had coffer dams been used, added to the many inconveniences that would have resulted from that mode of procedure, it was proposed to construct the outer pier and quays, forming the seaward side of the dock, without coffer dams.

This was effected in the following manner:—First, two parallel trenches were dug out to 17 feet below low water, for the foundations of the walls. A staging of timber piles was afterwards erected in the line of the pier over the whole breadth, for carrying the tramways, travelling cranes, and pile engines. Cast-iron guide piles (see Plates 34 and 35) were then driven from the staging with great precision 7 feet apart in the line of the face of each quay wall, till their heads were near the low-water line. They were then connected at the top transversely by wrought iron tie rods, stretching through the pier, cottered into sockets, and binding the heads together (see Plate 36). At first it was thought that there would be some difficulty in driving the iron guide piles with the required exactitude; but this was overcome by pile engines of peculiar construction, devised by Mr. William York, one of the contractors. These travelled on the rails of the scaffolding, and were furnished with long arms projecting downwards, strongly stayed by diagonals, and forming a trough, into which the piles were placed, one by one, and from which they were driven by the pile-engine, in the same manner as an arrow from a crossbow.

When the proper depth had been dredged out, and the piling driven, a bed of hydraulic concrete, 3 feet thick and 20 feet wide, was deposited in the trenches to form a base for the wall to spring from, and to give a large bearing surface.

Into the grooves formed by the flanges of the iron piles, large granite slabs, from 18 inches to 2 feet thick, were slipped, the bottom one resting upon the concrete base, and on a projecting web, cast on the piles. These form the face of the wall under water.

Behind this facing, hydraulic concrete was lowered in boxes with movable bottoms, and was discharged in mass to form the body of the wall. To confine this at the back before it had set, loose rubble stones were deposited and carried up simultaneously with it. The hearting of the pier, consisting of hard "till" stones and gravel was deposited afterwards, and the whole carried up to the level of low water.

After the entire mass—piles and stone facing, concrete backing and hearting—had been allowed sufficient time to consolidate, the heads of the iron piles and the granite facing blocks were capped at the level of low water by a granite blocking or string course; and the upper portion of the walls was carried up in freestone ashlar and rubble. The remainder of the hearting between the walls was then filled in, and the whole was finished with a granite coping and causeway.

The walls are 33 feet in height from the foundations, 11½ feet thick at the concrete base, and they diminish to 5 feet thick at the top.

The concrete used was composed of Arden hydraulic lime, iron-mine dust, sand, gravel, and stone chips; the lime and the mine dust being well ground under edge stone mills, before being mixed with the other materials. The proportions were by measure; one part of ground lime, half a part of mine dust, one part of sand, and three parts of gravel and stone chips. Immediately after being mixed, and when brought to a proper consistency with water, it was conveyed to where it was to be used, was let down under water in the discharging boxes, and in a short time set very hard.

EXTRACT FROM SPECIFICATION OF WORK.

GENERAL DESCRIPTION OF WORKS AND DRAWINGS.

The works are to consist of a pier formed in front of the Albert Quay, and the adjacent property to the east; and of a gangway communicating from this pier to the Albert Quay.

The positions of these works are shown on the general plan * * * (Plate 33).

The pier is to be formed of stone and concrete, and piling of iron, built in a trench dredged out for the purpose, and is to be built without the aid of a coffer dam, in the manner herein-after described.

The pier is to be 1,200 feet in length over all, measured along the centre line on top of quay, 60 feet wide in the body, and 88 feet at the ends across the return head; this return head is to be 53 feet broad.

Inside of the return head a flight of stairs, with two landings, is to be formed. Upright double timber fenders are to be placed at every 42 feet along both faces of the quays; and one double fender at each end, and corner fenders, consisting of five uprights and three sets of longitudinals, are to be placed at every corner of the quays.

Upright mooring palls, of cast iron, are to be set on the pier at both sides, at regular intervals of 42 feet.

The masonry is to be finished with a strong cope, and causewayed with coursed granite stone.

The gangway communicating with the Albert Quay is to be formed of timber piling, trussed and braced, and covered with a planked roadway.

* * * * *

It is to be supported by triple lines of timber piles at each end, leaving a space in the centre for boats and timber passing underneath. Each set of piles is to be braced across by ties and diagonals; the ties at the top forming also the cross joists. The piles of each side are to be braced and connected respectively to the pier and to the Albert Quay by horizontal ties bolted to the piles and fixed into the quays. The top longitudinal ties forming the bearing beams are to extend from quay to quay, and upon the top of these ties the cross joisting carrying the roadway is to be laid. The bearing beams are to be supported in the centre over the water space by diagonal and horizontal struts, as shown in the plans. Wing beams are to be set at the corners attached to the piles by cast-iron brackets, and built into the masonry of both quays, and supported on the quays and piles by diagonal struts. The joists under the roadway are to be dwanged with solid fillings. The roadway to be formed of planking, laid and fixed upon the joisting, and finished with an elm cope firmly fastened on the pile heads, and on the joisting over the wing beams. A covering board to be fastened over the ends of the cross joisting on both sides under the cope. A sleeper of timber is to be laid under the flooring plank ends where they overlap the pier and the Albert Quay, and a check cut out of the cope on the Albert Quay to receive the plank ends.

The whole of the woodwork is to be coated, when finished, with three coats of coal tar.

TIMBER WORK.

Quality of Timber.—The timber for the whole of the work, not specially mentioned otherwise, shall all be of American red pine, or memel, or of other wood approved by the Engineers.

The fenders and the cope of the gangways shall be of elm.

The whole of the timber must be of the best description, sound and free from sapwood, shakes, or injurious knots.

Gangway.—The whole of the piles to be shod with pile shoes of sufficient weight, having cast-iron points, with butts, not less than 4 inches square, accurately fitted to the pile point, and fastened by malleable iron straps and spikes.

The piles must be fair, straight, and equal, and stand 12 inches in the square throughout.

The whole of the piles must be driven down to, and stand the full length described, after they are driven, and the hoop ends cut off. This must be taken into account by the contractor, and allowance left for waste and all contingencies in the length of sticks provided.

Any piles that do not range in line, or that are not in winding with one another, or which may otherwise be improperly driven, must be drawn, and if sound, re-driven; any pile which may be shattered, split, or otherwise injured must be drawn, and sound piles substituted in their places.

The piles must all be driven by steam-pile engines, with rams of sufficient weight, and with sufficient head of fall, to the satisfaction of the Engineers.

The under cross-ties and diagonals to stand 12 × 4 inches, checked $\frac{3}{8}$ inch upon the piles; the top cross-ties same size, the pile-heads checked $\frac{3}{4}$ inch to receive them. The ties to be fastened by two $\frac{3}{4}$-inch bolts through each pile.

The longitudinal ties connecting the piles to the quays, and the bearing beams under roadway joists, to be 12 × 6 inches, the former checked out half an inch for the piles, and the piles checked half an inch for the latter, to be fastened by two $\frac{7}{8}$-inch bolts to each pile.

The lower ties must be in single lengths, the upper beams in one length over the water space, and scarfed to the end lengths, and secured by an iron plate over

the scarf, 3 feet long × 10 inches × ½ inch. These beams are to be set 18 inches into the masonry at each end, filling pieces 18 inches long, to be fixed between the double ties over the water space, fastened by two ¾-inch bolts.

The upright filling pieces on the side of piles between the runners to be fitted in tightly, and fastened by two ¾-inch bolts.

The horizontal and diagonal bearing struts to be butted, fitted, strapped, and bolted firmly together, and to the piles and ties; diagonals, 14 × 12 inches; horizontals, 12 × 11 inches.

The wing beams and diagonals to be 12 inches square, fitted and set on masonry, and secured to piles by cast-iron brackets, all firmly bolted together.

The cross-joists for the roadway to be 12 × 4 inches, dressed on top for roadway, firmly spiked to the longitudinal beams; those crossing the piles firmly bolted to them, as before described.

Five lines of dwangs, being solid cuttings, 3 inches thick, to be fitted and firmly spiked between the joists.

The planking of the roadway to be 4 inches thick, in long lengths, spiked by an 8-inch spike at each crossing; the butts to break joint; no two butts falling on the same joists; the joists planed and fitted tight; and the joints and butts caulked with oakum and payed with pitch.

The elm cope to be in long lengths, scarfed at the joinings; scantlings 12 × 9 in., rounded on the edges and cleaned, top, bottom, and sides; the outer line of piles to have tenons cut upon them, and the cope morticed and fitted on the pile-heads, and fastened by a ⅞-inch clinch bolt, not less than 3 feet long, or by a wood screw. The cope at the wings to be fastened to the bearing beams by ⅞ in. bolts.

The covering plank on ends of joists to be 18 × 3½ inches, firmly spiked to each joist and to the beams and cope. The heads of all bolts in the cope to be countersunk, and the hole plugged with wood and red lead.

Throughout the whole of the woodwork all ties and runners shall be scarfed at the joinings, no butt joints being allowed anywhere except on the flooring.

All butt joints and crossings on the runners, diagonals, cross-ties, joists, struts, uprights, dwangs, planking, and cope, and the bottom and sides, and butts of planking, in fine, every part in which one piece of wood crosses or comes in contact with another, shall receive a coat of Archangel tar before being put together, and the entire surface of the timber work above low water shall receive two coats of coal tar, and the roadway shall be tarred and sanded.

Fenders.—The fenders to stand 12 inches square, after being sawn and dressed perfectly fair and straight, to be half-rounded on the ends, and fitted fairly to the stonework. The horizontal filling pieces of the end fenders to be accurately fitted between the uprights, and dressed in the same manner.

The holding studs for the fenders are to be batted 12 inches into the wall, and run up with lead, and the holding bolts passed through the fenders, filling pieces, and studs, and clinched.

Platform under Mooring Palls.—The battens for timber platform under mooring palls to be 4 feet long × 7½ inches × 2½ inches, one set crossed over the other, and firmly spiked at each crossing; the ground below filled in with gravel well punned.

IRON WORK.

The whole of the castings must be sound and free from air-holes or flaws of any description, and made to the forms shown on the drawings, and to the full dimensions shown or described. The forgings must be made from best iron.

Coating of Piles.—The piles, after being carefully cleaned from all sand and extraneous matter, and after inspection by the Trustees' inspector, are to be coated throughout with coal pitch and oil, according to Dr. R. A. Smith's patent process. The piles are to be immersed in a trough, taking in an entire pile at once, the preparation being kept at a temperature of 300° Fahrenheit, and each pile kept in the trough for 30 minutes. The piles must not have been exposed to the weather, and no rust must have been allowed to form before the coating is given. The operation is to be performed under inspection of a party appointed by the Trustees.

Coating of Mooring Palls.—The mooring palls are to be coated with the same preparation outside and inside, but are only to be dipt into the preparation, which is to be kept at the same heat; and the whole of the tie-rods and braces are to be coated in the same manner.

The contractor shall pay the expense of royalty for the patent.

Piles.—The side and end piles to be H shaped, the corner piles E shaped; to have bosses on upper ends, with cotter holes for receiving the tie-rods. The piles must be straight, fair, and equal, from end to end, and free from any lumps or projections; they must be accurately entered, and set to the guides above and below, and driven in position fair, and out of winding with one another, and to the exact gauge, driven plumb on sides, and sloped on face to an inclination of one foot in ten. The heads of the piles must be protected from the ram, whilst being driven, by a cap. The weight of the ram and the length of the stroke must be adjusted to the satisfaction of the Engineers. Any piles which may be injured in driving, or which may be improperly driven, or which may, from any cause, get out of place, must be drawn

and replaced. The piles must be driven to the full depth shown. Should any boulder stones, or other obstruction, be met with near the surface, such must be cleared out and removed, so as to allow the pile to pass. But should the pile come upon a boulder stone after being driven not less than five feet into the ground below the bottom of the trench, the pile may be drawn and a shorter pile substituted, otherwise the pile must be driven to the full depth described.

The heads of the piles, and the shelf at the lower end for receiving the granite slab, must each be brought respectively to the exact same lines and levels.

Tie-rods.—The tie-rods and diagonals and pins and cotters shall be of best Govan iron, swelled at the cotter ends, and the cotter holes cleanly cut out; the rods are to be in two pieces; the ends which meet in the centre of the quay screwed with reverse screws, fitted with a double screwed cramp, for the purpose of tightening up the tie. The diagonals for corners to be flat iron, 4 inches × 2 inches, having holes to receive the pins of end ties; the ends of the diagonals are to be jointed to a 3-inch square bat, sunk into one of the side granite slabs, the end of the bat dovetailed and slit, and fitted with a wedge driven hard in and run up with lead.

Bats.—The bats in the lower stone to be made and fitted in same manner of 2-inch square iron; the iron bars for banding to the concrete to be 7 feet long × 4 inches × 1 inch, with a cross tail on end, of same size of iron, 3 feet long.

Mooring Palls.—The mooring palls are to be of cast-iron, of the form shown, and set on the timber platform in exact position, plumb and in line, and built in with the masonry.

MASONRY AND CONCRETE.

Quality of Stones.

Granite Slabs.—The stones for the face of walls below low water shall be solid slabs of granite.

Granite Ashlar.—The stringing course of stones over pile-heads and the cope stones, and the steps of stair, shall be of granite ashlar.

Freestone Ashlar.—The stones for the front of walls above low water, with the exception of the cope and blocking course, shall all be square ashlar blocks, of the best beds of Nitshill or Giffnock, or other stone of equal quality submitted to the Engineers, and approved of by them in writing. They must be hard, and free from drys or flaws of any description, and must all be laid on their natural beds.

Quality of Granite.—The whole of the granite stones must be sound and free from flaws. The cope stones must be of one colour throughout.

Rubble Backing.—The dry rubble wall at back of concrete below low water shall be rubble, of mixed sizes of good sound stones.

Rubble.—The rubble backing of walls above low water shall be large blocks of sound stones.

Causeway.—The stone for causeway shall be of squared blocks of granite, of equal size and quality, and according to sample to be seen at the Engineers' office.

Lime, Mine Dust, Sand, and Gravel.

Lime.—The lime for the concrete and mortar shall be entirely Arden or Davieland hydraulic lime, obtained from the quarries near Pollokshaws or Thornliebank, or of blue lias lime from Aberthaw, brought unburnt to the works, as the Engineers may decide; and no other lime of any description shall be allowed to be brought on the ground on any pretence whatever. The Arden or Davieland lime must be obtained hot from the kilns, and placed in covered trucks or carts, and sent direct to the works, and discharged immediately into the covered lime store. If Aberthaw lime is used it must be burnt in kilns at Greenock. No lime will be allowed to be used which has not been kept perfectly covered from the time of leaving the kilns until its arrival at the works. Should the lime require to be carted after its arrival in Greenock, it must be removed direct out of the trucks into covered carts expressly arranged for this purpose.

Lime Shells.—The lime shells shall be brought from the kilns in quantities as it may be required, and must not be allowed to accumulate in too great quantities at one time; they shall be ground to fine powder under the edge stones and stored upon the asphalte floor; the mine dust shall also be ground and laid aside.

Sand and Mine Dust.—The sand shall be clean, sharp, and large-grained, perfectly clear of dirt or earthy matter.

The mine dust must be pure and free from dirt, and is to be ground under edge stones before being mixed with the lime.

Gravel and Quarry Chips.—The gravel for the concrete shall be of equal size, no piece larger than will pass through an iron ring 2½ inches diameter, the quarry chips broken to same size. The gravel must be washed perfectly clean.

Grinding Machinery and Lime Store.

The building and machinery, and arrangements for the lime and mine dust grinding and mixing, must be furnished and constructed by the contractor, all made according to the plan furnished for the purpose by the Engineers. The lime store must be built of brick, and roofed with tiles or slates. The floor asphalted over the portion set apart for the ground lime, none of which shall be allowed to be laid on the

bare ground. The grinding mill to consist of edge stones 48 inches diameter, of which there must be at least one pair erected under the roof of the lime house. The mortar mills shall also consist of edge stones, of which there must be at least two sets erected under cover in the positions shown. The mine dust must be ground under edge stones, of which one pair must be erected in some convenient situation. A platform of timber or asphalte shall be laid before the mills, upon which the lime, sand, and mine dust will be delivered ready to go through the mill. A dry mixing cylinder of sheet iron, driven by the engine, shall be placed in position shown, for mixing the material for the concrete. The whole of the machinery shall be driven by a steam-engine of sufficient power.

Mortar.

The mortar shall be composed of ground lime, sand, and ground mine dust, in the following proportions :—

1 part ground lime, by measure.
½ part ground mine dust, „
1 part sand, „

The measuring of the materials in the proportions specified for the mortar shall be proceeded with at a stated hour each day, and no measuring of materials shall take place on any account without the presence of an inspector; otherwise, in any such case, the contractor shall be bound to remove such meted material at once from the works, on receiving notice from the inspector.

The materials shall be filled into box measures at their respective heaps, and brought forward upon the mixing platform, and mixed in a dry state, and discharged upon the covered platform before the mortar mills.

The dry mixture is then to be placed under the edge stones, and mixed with water for not less than 15 minutes for each delivery, and shall then be immediately sent down in boxes for the use of the works. No more lime must be mixed than can be used up in one day, any mortar mixed on a previous day must be removed from the works at the inspector's orders.

Concrete.

The concrete shall be composed of ground lime, ground mine dust, sand, and gravel, and quarry chips, in the following proportions :—

1 part ground lime, by measure.
½ part ground mine dust, „
1 part sand, „
3 parts gravel or quarry chips.

No concrete shall be allowed to be used of which the materials have not been carefully measured under the supervision of an inspector; any concrete mixed otherwise will not be allowed to be used, but must be removed at once from the works at the inspector's orders.

The lime, sand, and mine dust, for the concrete, shall be measured and mixed dry in the same manner as the materials for the mortar, the gravel being also measured and cast into the cylinder, and then discharged into a trough, and watered and thoroughly mixed, and filled into the discharging boxes.

No concrete which has been mixed on a previous day shall on any account be allowed to be used on the works. Before any concrete shall be laid, the ground must be carefully examined by the divers, and cleaned thoroughly out, and the bottom levelled and prepared to receive the concrete. The ground shall then be examined by the Trustees' inspector; and when his certificate, stating that the ground is ready to receive the concrete, has been given, the laying of the concrete shall be commenced; but no concrete shall be permitted to be laid in any part of the works before the site has been so examined and certified by the inspector.

The concrete is to be lowered in boxes provided with moveable bottoms, which shall not be discharged until they reach the bottom, it shall then be carefully spread and packed by the diver in layers of about 12 inches deep. The concrete shall in the first place be laid in front of the trenches, packed well underneath the granite slabs and around the piles, and sloped up the face of the stones. The stone backing as herein-after specified shall be carried up in layers along with the concrete. Care must be taken that no extraneous matter from the banks or elsewhere gets into the trenches whilst the concrete is being laid. The concrete shall be laid regularly and continuously and no spaces or voids left, but all must be uniformly and equally filled and properly backed up against the stone facing and rubble backing, and well rammed as before specified.

Mason Work under Low Water.

Granite Slabs.—The granite slabs in each compartment shall be in not more than three depths, each filling up the entire space from pile to pile. These slabs to be 6 feet 9 inches broad, 18 inches thick, and none to be less than 4 feet deep. The beds and ends of each slab shall be margin-drafted with the chisel, and pick-dressed fair within, the front and back left with the natural quarry face. The ends shall be thinned to 10 inches, and squared in on both faces to a breadth of 4 inches to fit the grooves of the iron piles. These faces shall be drafted square with the chisel and close pick-dressed. The slabs must be carefully and accurately fitted and set by cranes of sufficient power, and the top beds of the upper stones brought to exact line and level.

Rubble backing for Concrete.—The dry rubble stone wall behind the concrete is to be laid in layers of not more than 12 inches deep. Before commencing to a course, boarding adjusted to the exact position must be set against the front to guide the laying and to keep the stones from falling into the concrete, and removed as the courses are laid. After each course is laid this boarding shall be removed and a course of concrete laid. The courses of stones must never be advanced more than 18 inches above the surface of the concrete.

Mason Work above Low Water.

Stringing Course.—The granite ashlar string course shall consist of stretchers, each 7 feet × 2 feet 6 inches × 18 inches, chisel-drafted on beds, joints, and face, and pick-dressed fair within the margin; the outer edge of upper bed to be chamfered one inch.

Flag Course.—This string course to be backed right across the wall with a flag course of quarry-dressed freestone.

Ashlar Freestone.—The upper courses of ashlar freestone, chisel-drafted on face, beds, and joints, and dressed fair within. The edges of upper and under beds to be chamfered one inch. The courses to consist of two stretchers to one header; the headers set eight feet apart from side to side. Headers to be 3 feet long × 36 inches × 16 inches; stretchers 21 inches broad × 16 inches deep. The headers of each course of ashlar must be placed upon a stretcher of the course below; no joint nearer than 12 inches to the joint of any header in the lower course.

Dressing of Ashlar.—The stones, both of granite and freestone, must be square-dressed throughout, and carry their thickness and depth right through to tail and back.

Cope.—The granite cope to be 5 feet to 4 feet × 3 feet × 18 inches, chisel-drafted on face, beds, and joint, and close pick-dressed fair within; to be rounded on top edge, and chamfered on under edge, doweled at the joints with square cast-iron dowels, 6 inches long and 2 inches on the side; the groove in each stone to form a **V**, and to be run in with Portland cement. No cope to be built under the portion of the quay upon which the planks of the gangway rest, but the wall under the flooring to be made up with ashlar, to be finished with a timber sleeper on top, to receive the planks of roadway.

The cope of the Albert Quay to be checked out for the planking, and dressed fair.

Ashlar Building.—The ashlar stones are all to be laid flush in mortar, each stone laid solidly on the stone beneath, without any pinnings, and the vertical joints flushed up with mortar and grouted; the stones must all break joint; beds, and joints of face of walls, to be bedded 2 inches from the fronts with Portland cement, and drawn in.

Rubble Building.—The rubble stones are all to be laid in level beds, having plenty of bond stones flushed perfectly up with mortar, and solidly packed with large packing, and every crevice filled in with mortar and in addition grouted at every levelling; the beds must be levelled at least at every second course of ashlar. The cross joints must be all properly broken and bonded; bond stones, not less than 3 to 3½ feet, must be set 8 feet apart at least. Back of walls to be pointed throughout with Roman cement.

Pointing.—The whole of the work, both face of ashlar and back of rubble, to be pointed.

Stairs.—The stairs to be of granite; the steps and landings chisel-dressed and checked into the sides of wall, and doweled to one another at the joints with cast-iron dowels.

Filling in between Walls.

The best and hardest of the material obtained from the dredging, which may be approved by the Engineers or inspector, is to be used for filling in between the walls, and is to be mixed with gravel and rubble in the proportion of one part of gravel and rubble stones to two parts of dredged material. The filling in must be proceeded with at such times and in such manner as the Engineers may direct, and executed to their satisfaction. When the work is filled in to the level of low water it must be allowed to consolidate for such time as the Engineers may direct before the filling in of the upper portion is proceeded with.

Causeway.

Gravel Bed and Concrete.—The embankment, after having been allowed to settle completely down, is then to be covered to the depth of 12 inches with gravel and sand firmly beat down. A bed of concrete 12 inches deep is then to be laid above this, covering the entire space under the causeway.

Stones.—The granite stones are to be 10 inches × 4 inches × 6 inches deep, laid in a bed of lime mortar in regular courses, to the exact curve on surface, firmly beat down, and the joints filled in with lime mortar and grouted, and a thin layer of gravel spread over the surface.

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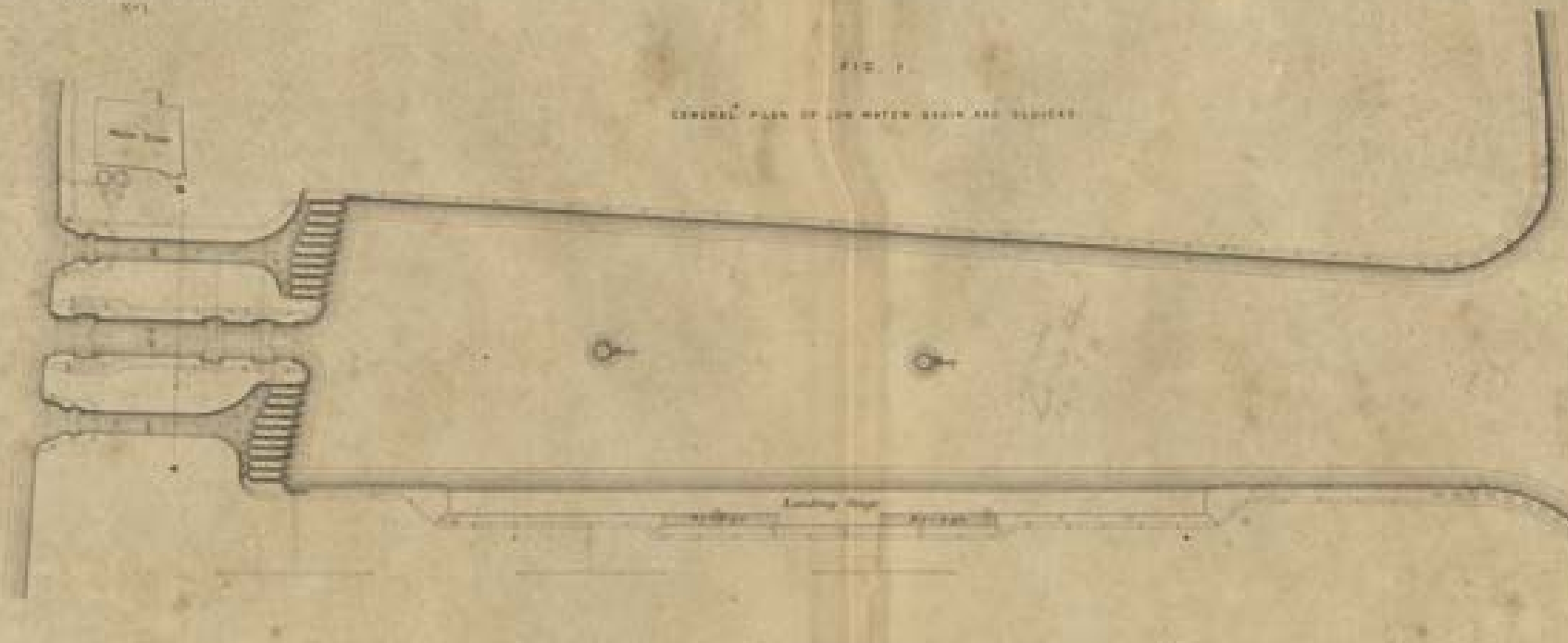
BIRKENHEAD DOCKS.

LOW WATER BASIN

N°1.

FIG. 1.

GENERAL PLAN OF LOW WATER BASIN AND SLUICES.



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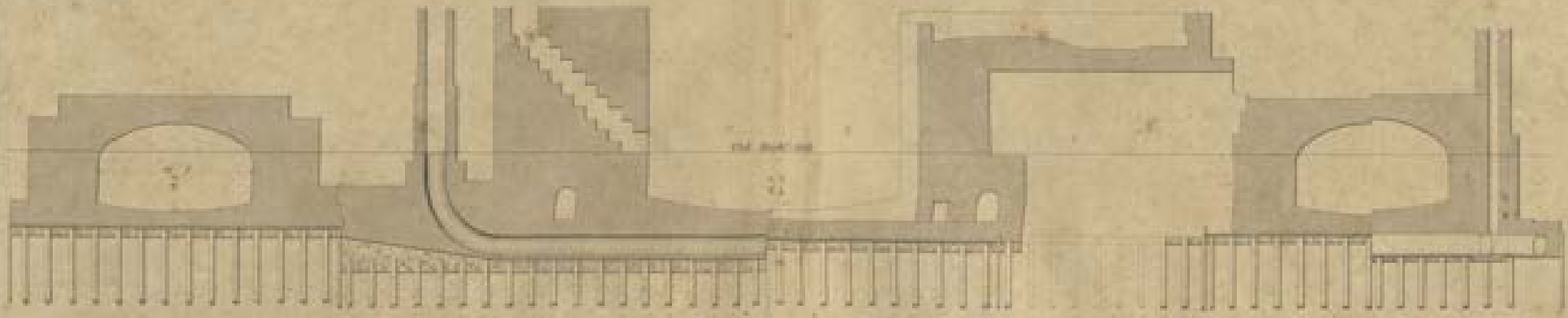
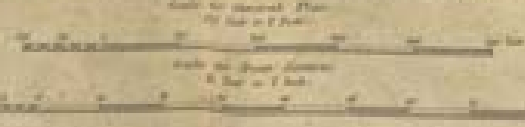




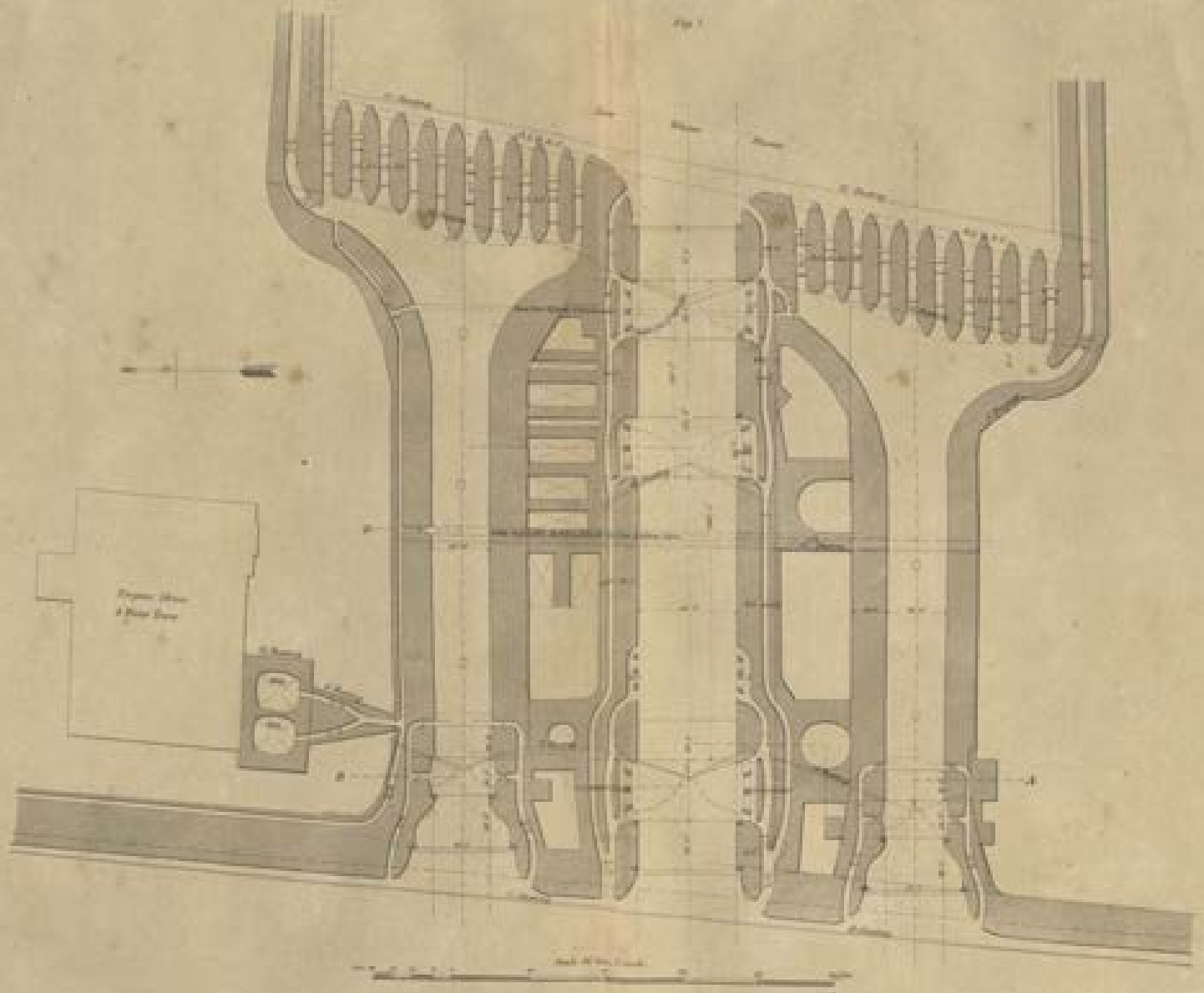
BIRKENHEAD DOCKS.

LOW WATER BASIN.

No 2.

PLAN OF OUTLET LOCK AND DOCK GATES.

Fig 1.

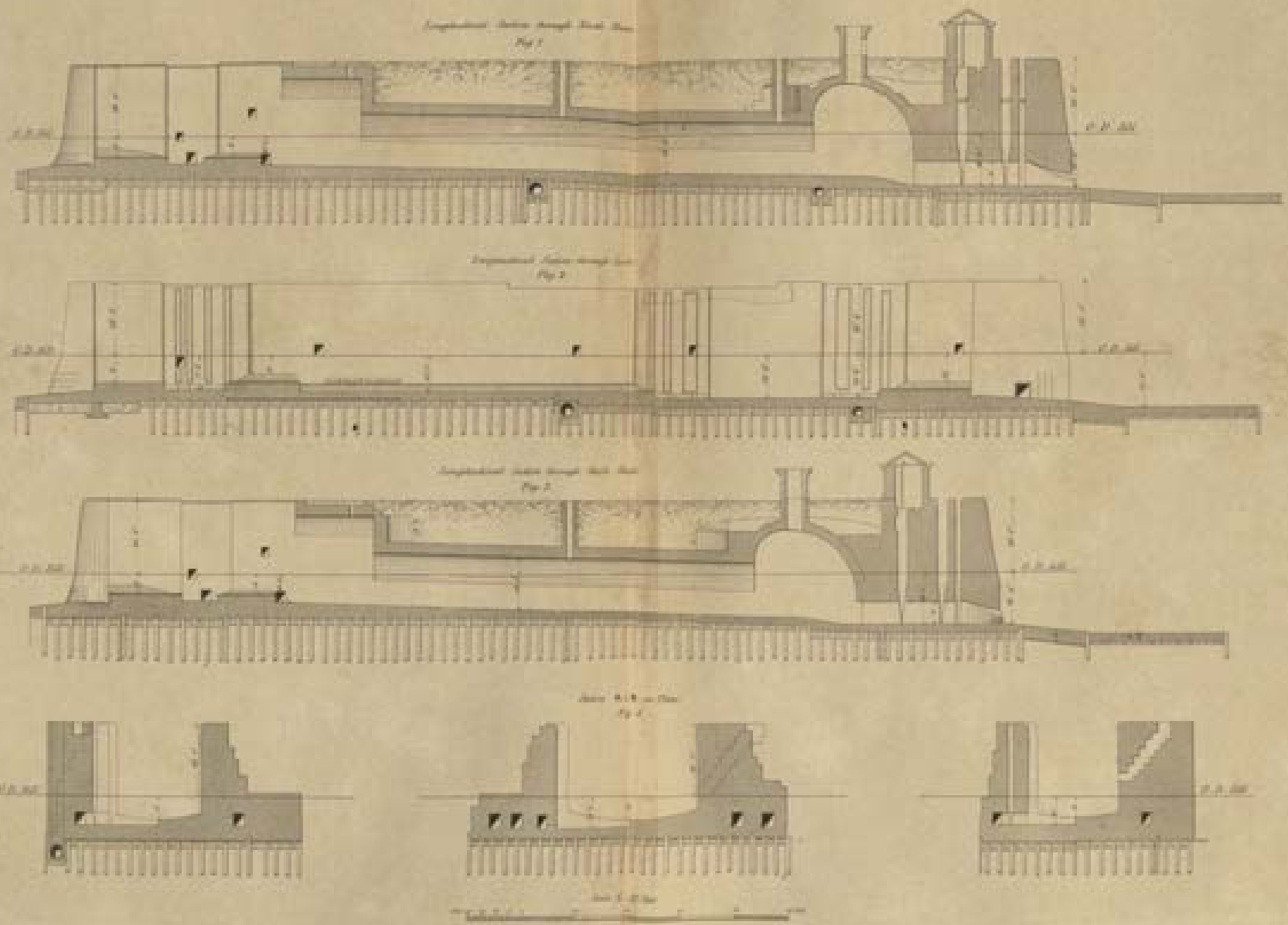


BIRKENHEAD DOCKS.

LOW WATER BASIN.

No 3

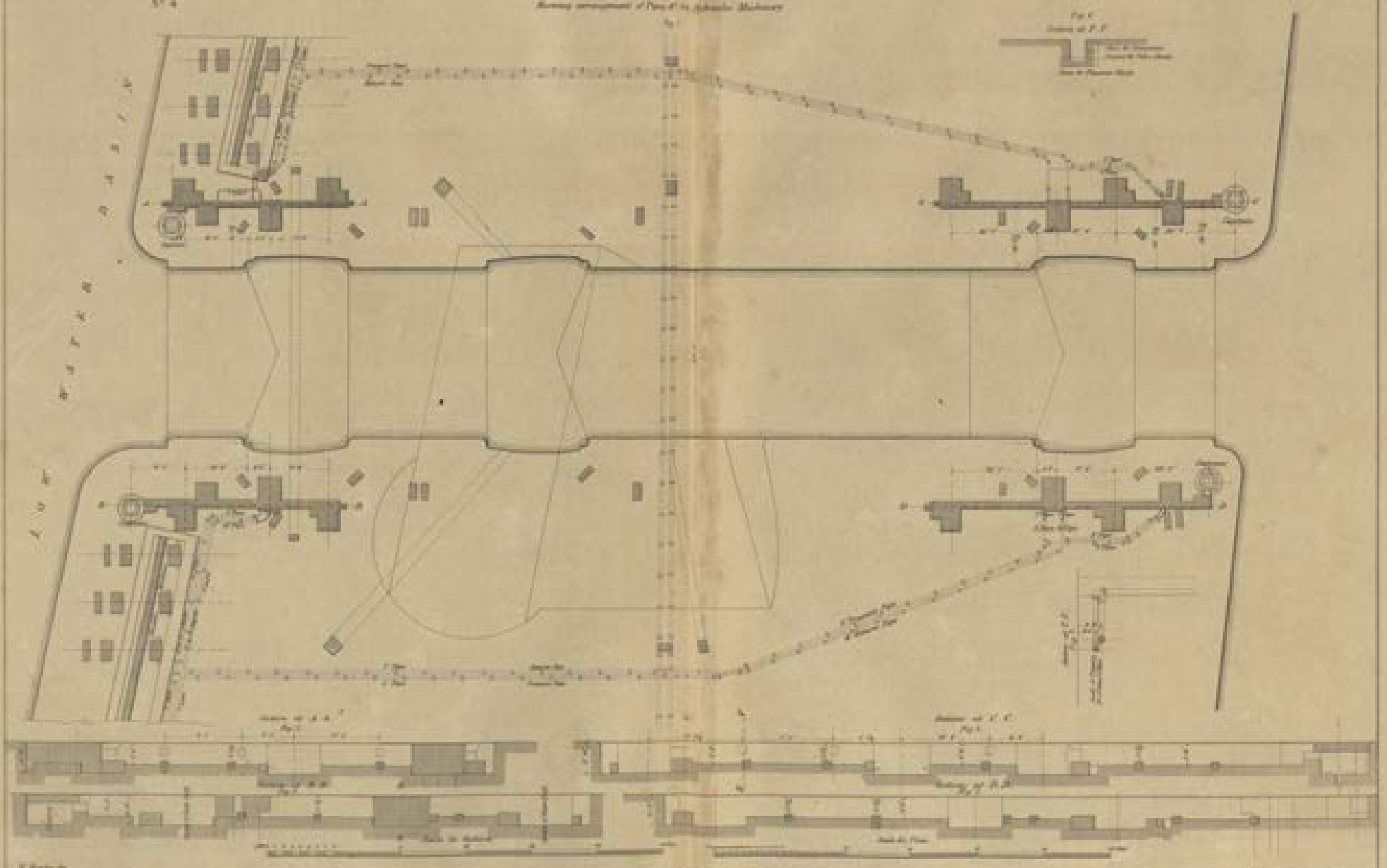
DETAILS OF WORKS



BIRKENHEAD DOCKS.

LOW WATER BASIN.

N° 4



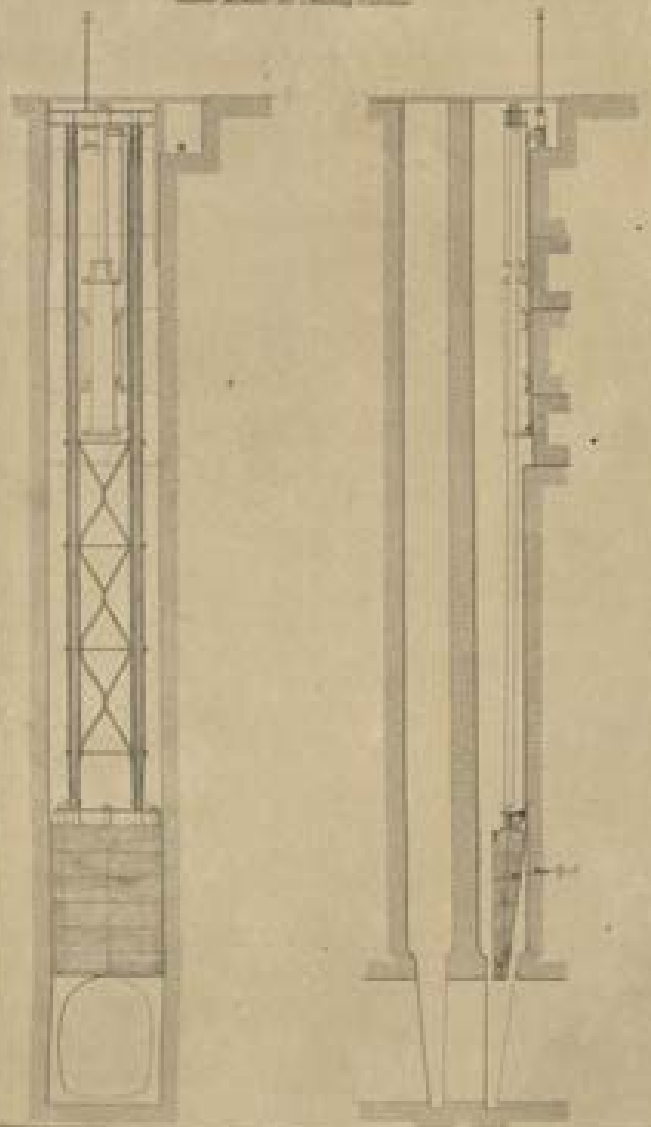
BIRKENHEAD DOCKS.

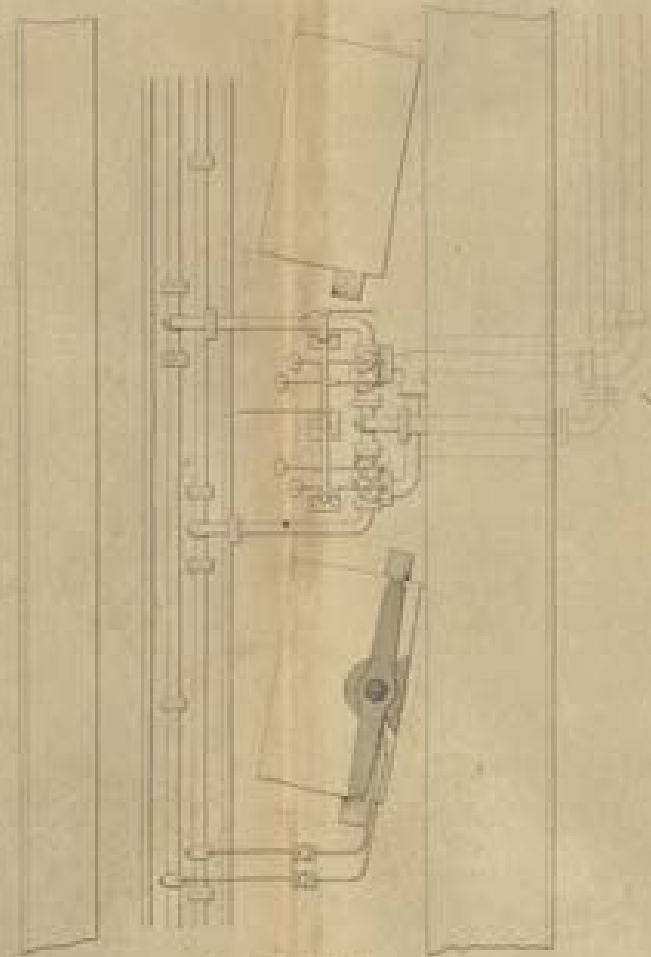
LOW WATER BASIN.

DETAILS OF SWING BRIDGES.

Plan of Swing Bridges

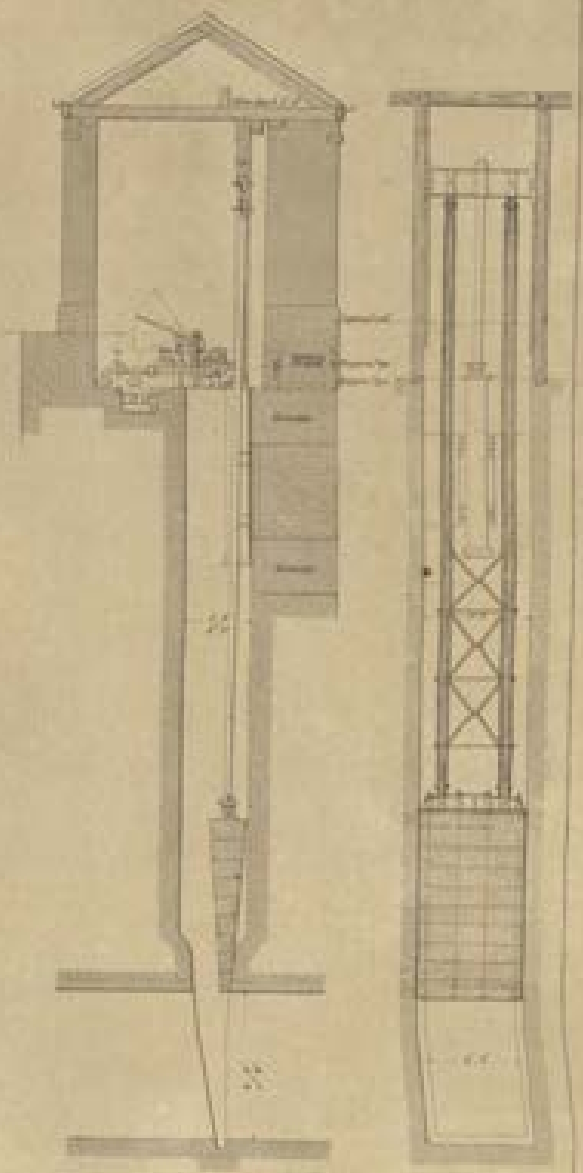
Swing Bridges for Landing Platforms





Scale for Plan of Swing Bridges

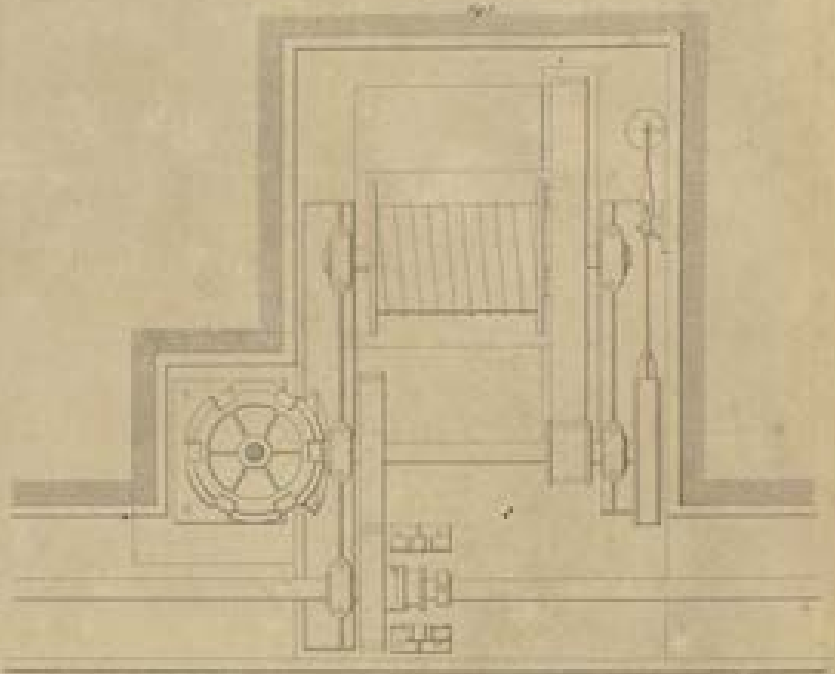
Swing Bridges for carrying and during Carrying Railway

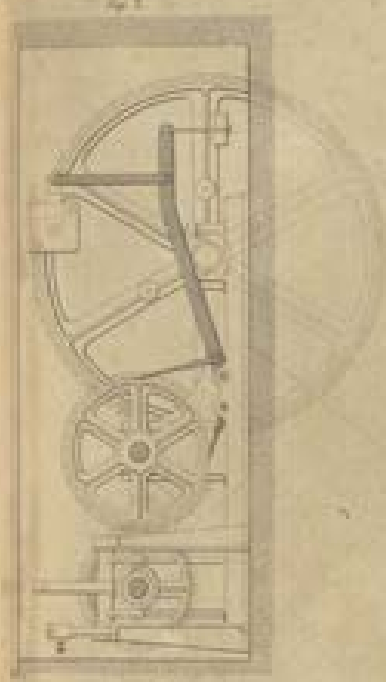


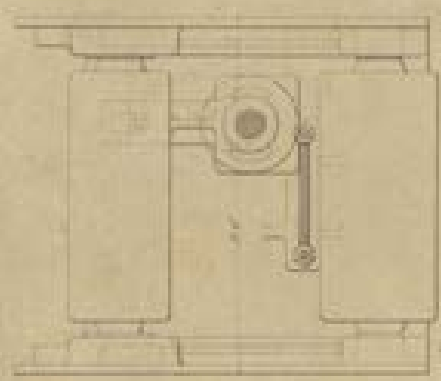
BIRKENHEAD DOCKS.

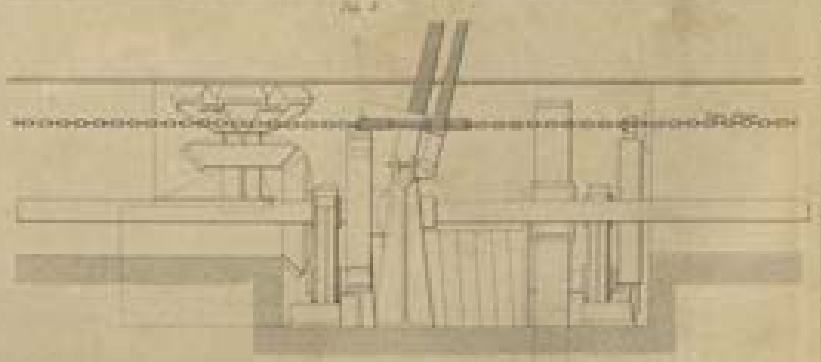
LOW WATER BASIN

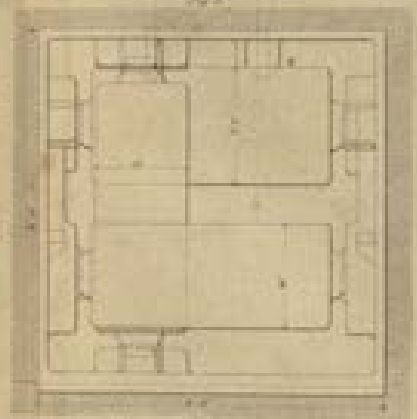
STR

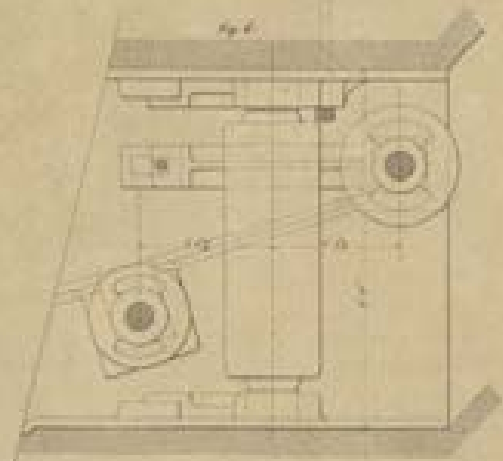






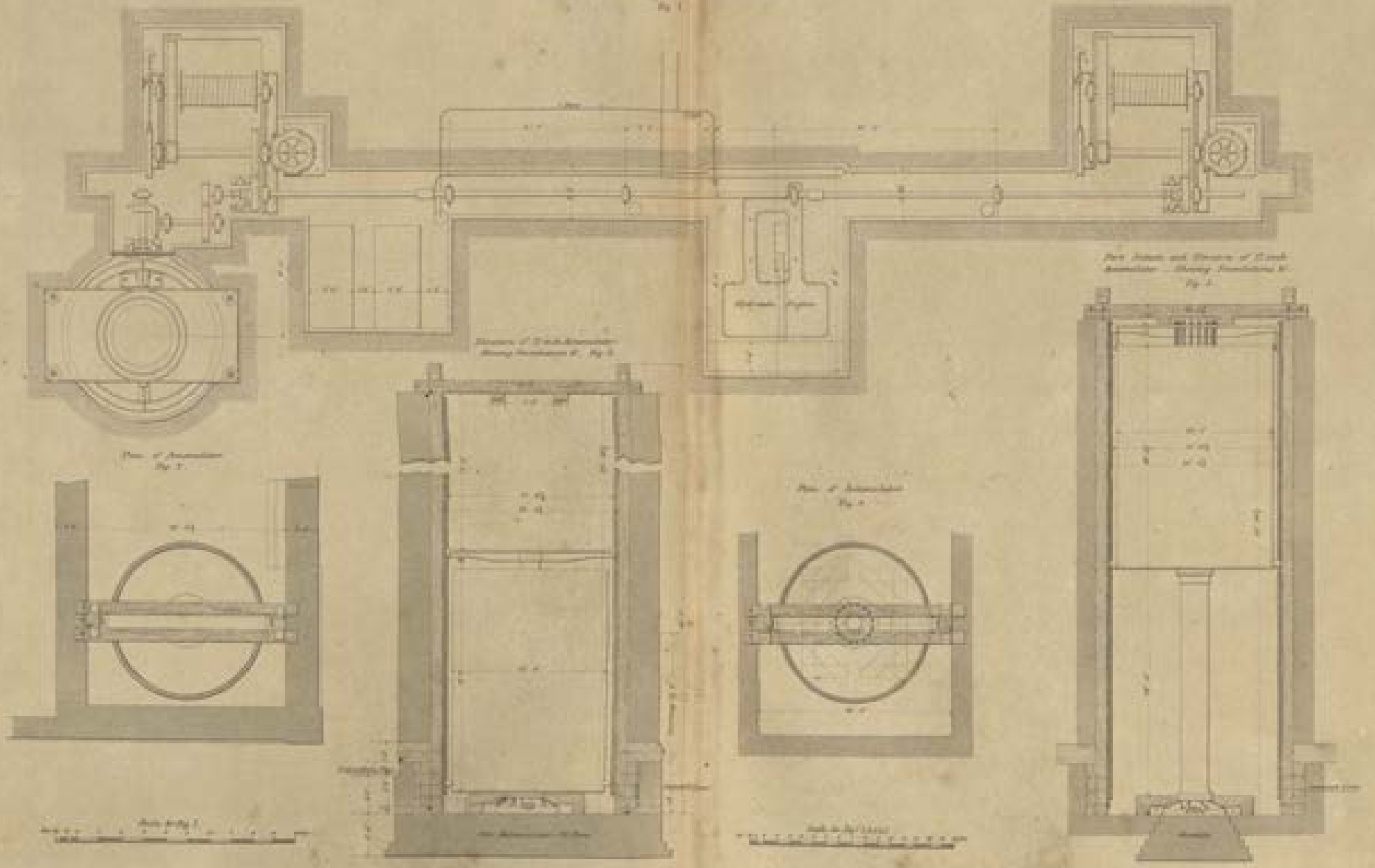






BIRKENHEAD DOCKS.

LOW WATER BASIN.

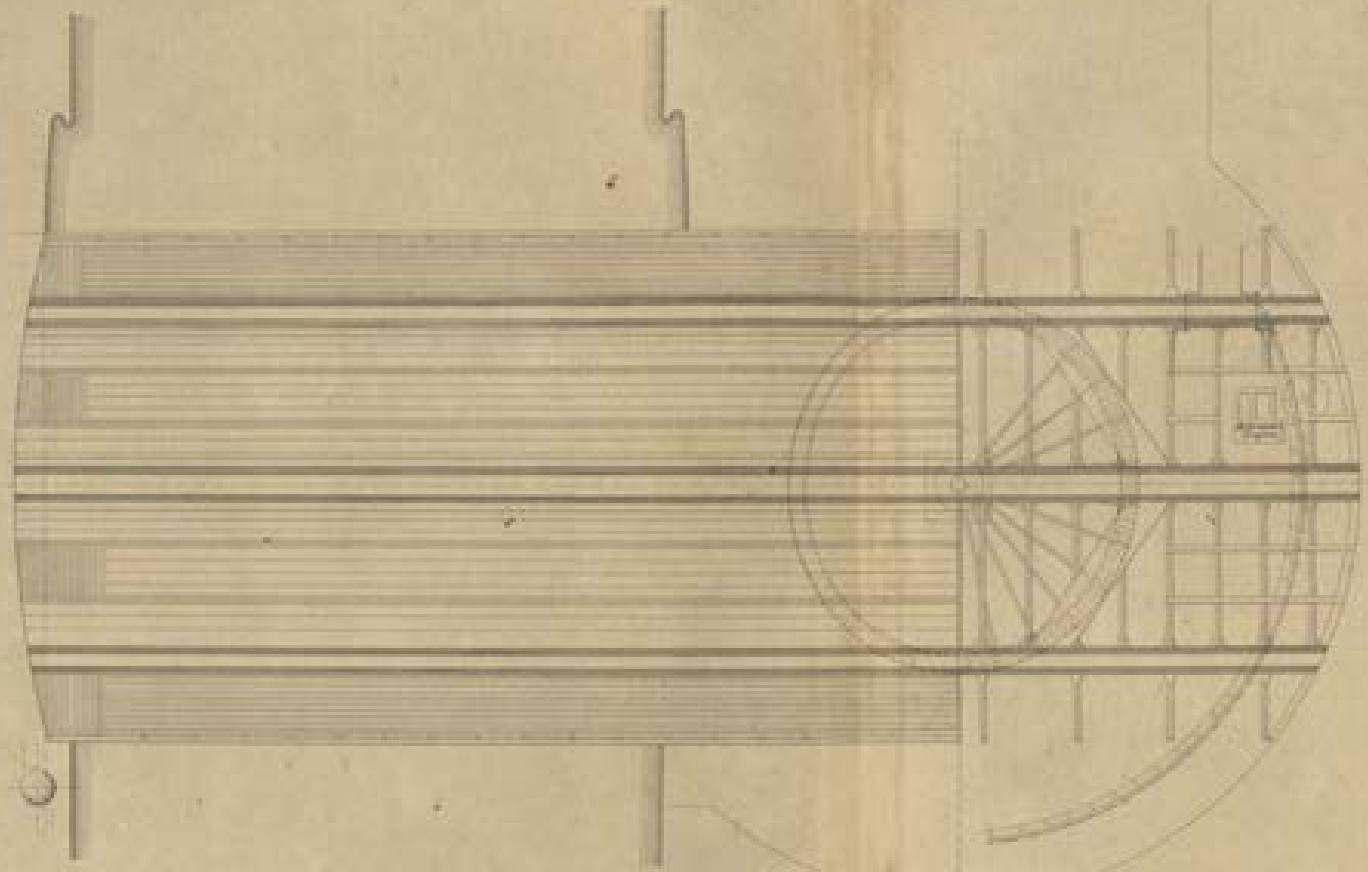


BIRKENHEAD DOCKS.

LOW WATER BASIN.

SWING BRIDGE OVER NO 2 DOCK LOCK

PLAN



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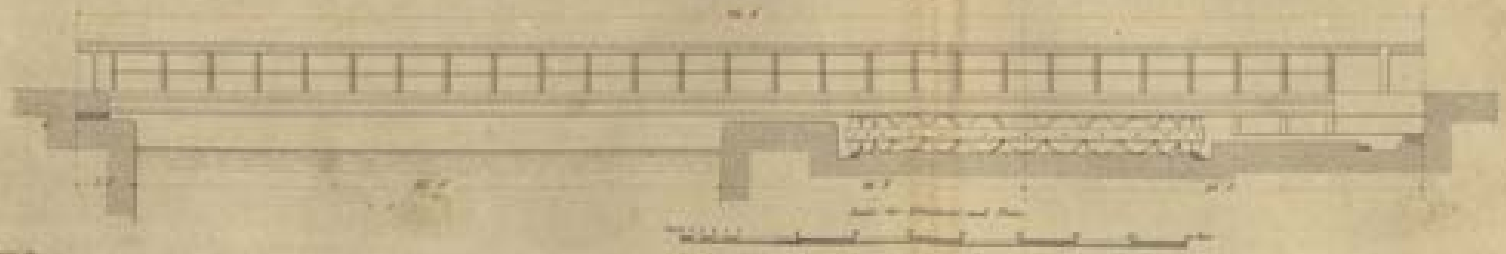

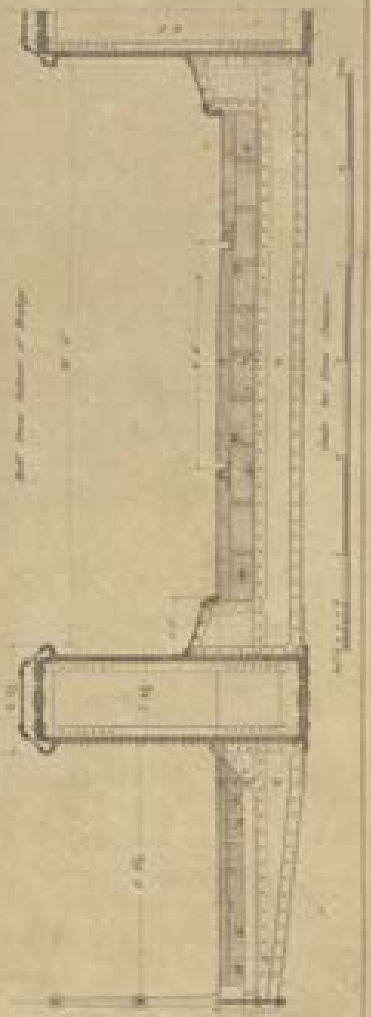

BIRKENHEAD DOCKS.

LOW WATER BASIN

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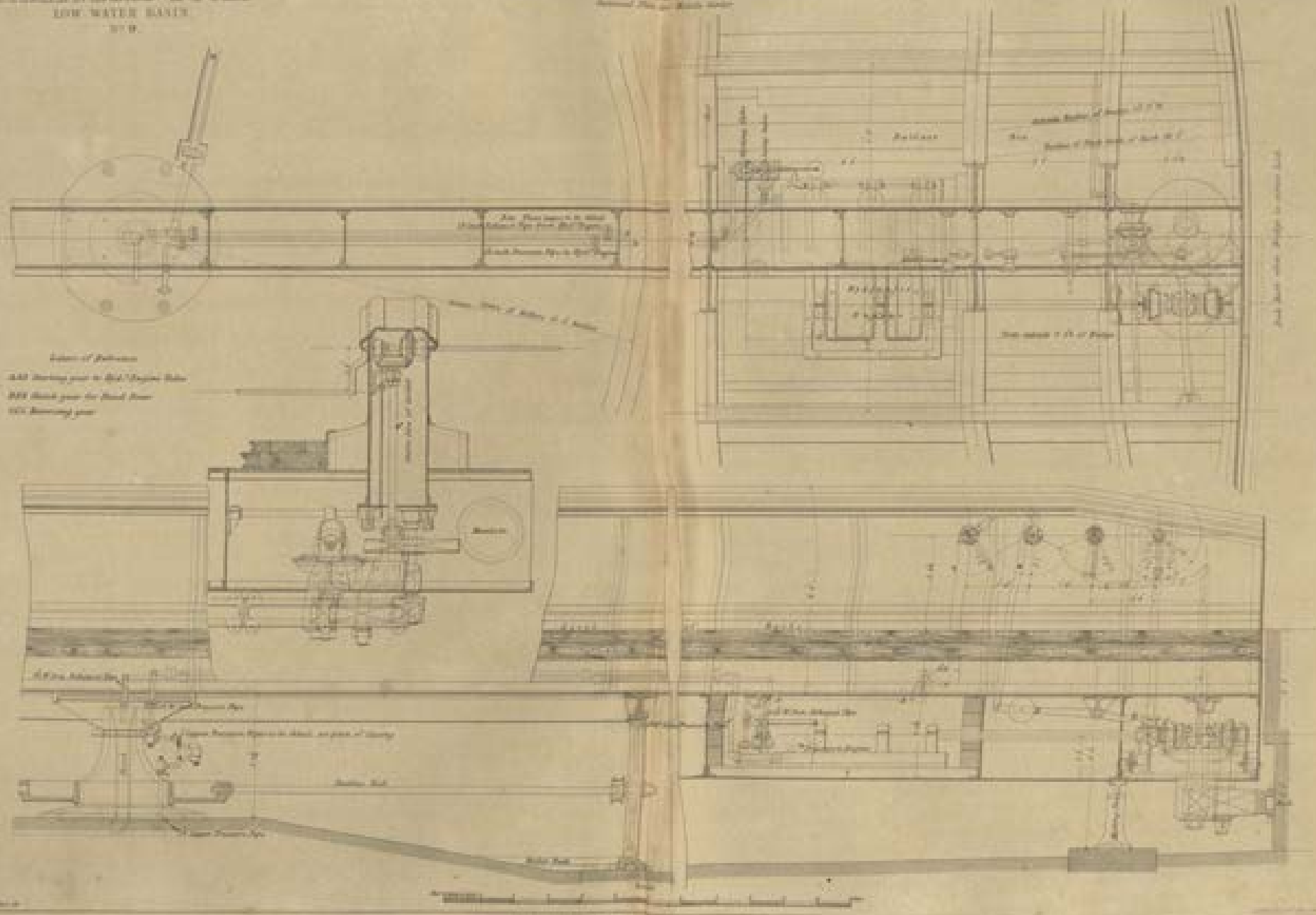


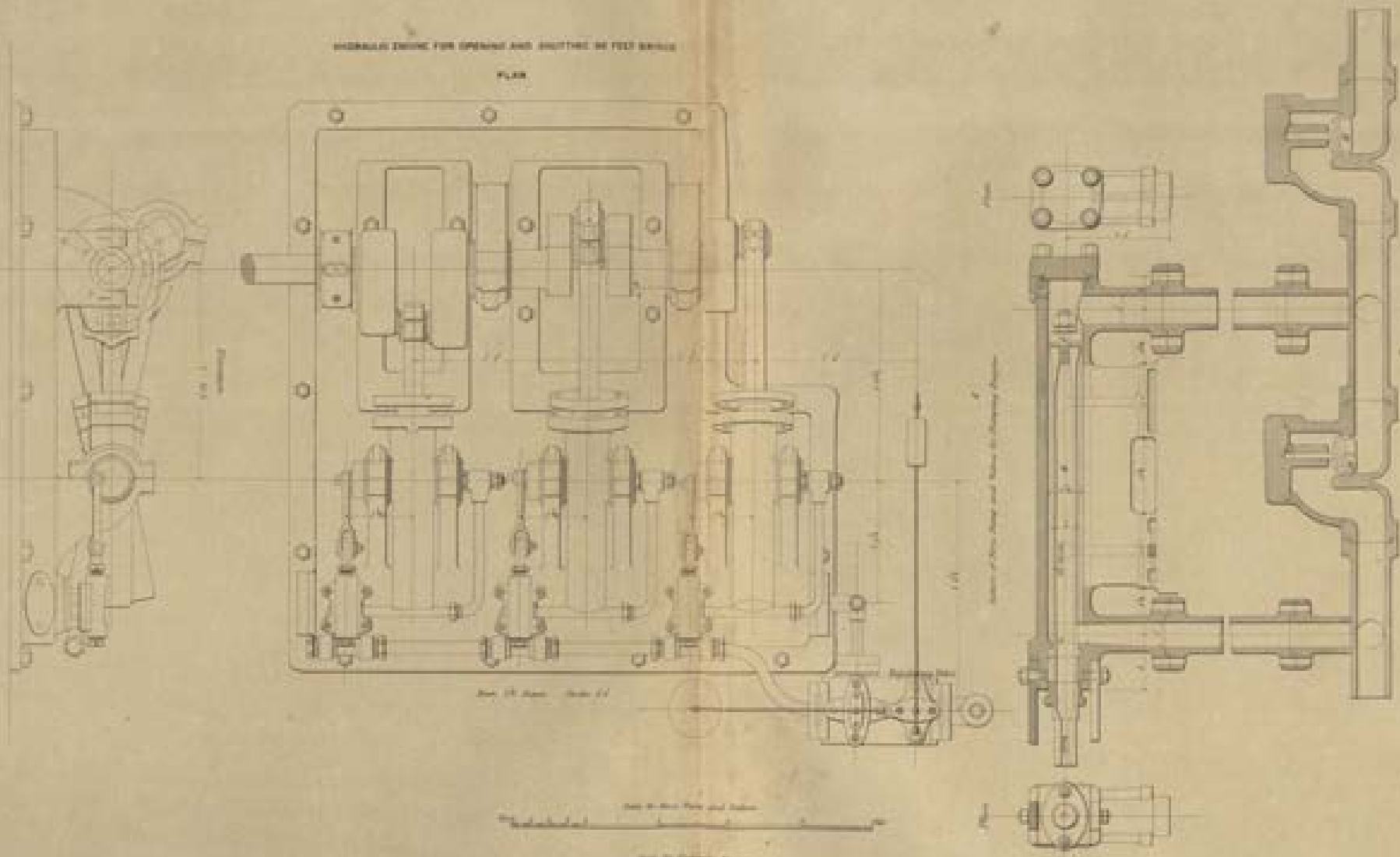
BIRKENHEAD DOCKS.

LOW WATER BASIN.

N°20.

HYDRAULIC ENGINE FOR OPENING AND SHUTTING 66 FEET GATES.

PLAN



BIRKENHEAD DOCKS.

LOW WATER BASIN.

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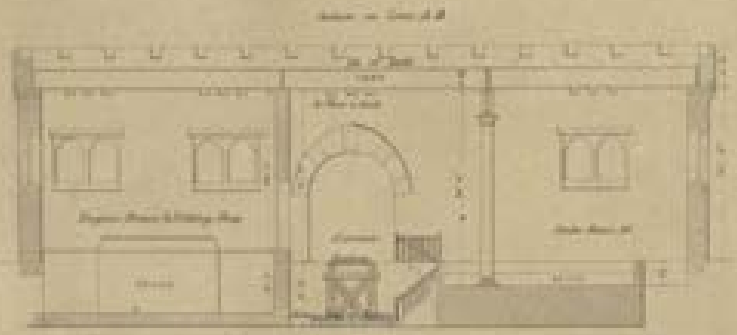
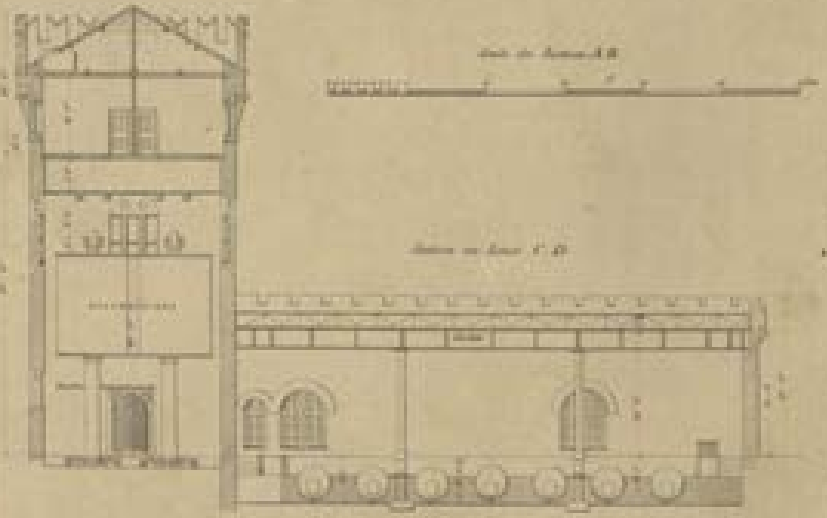
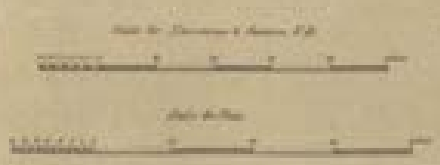
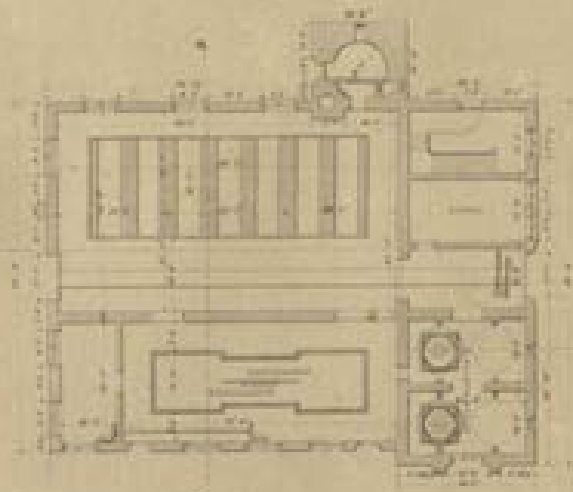


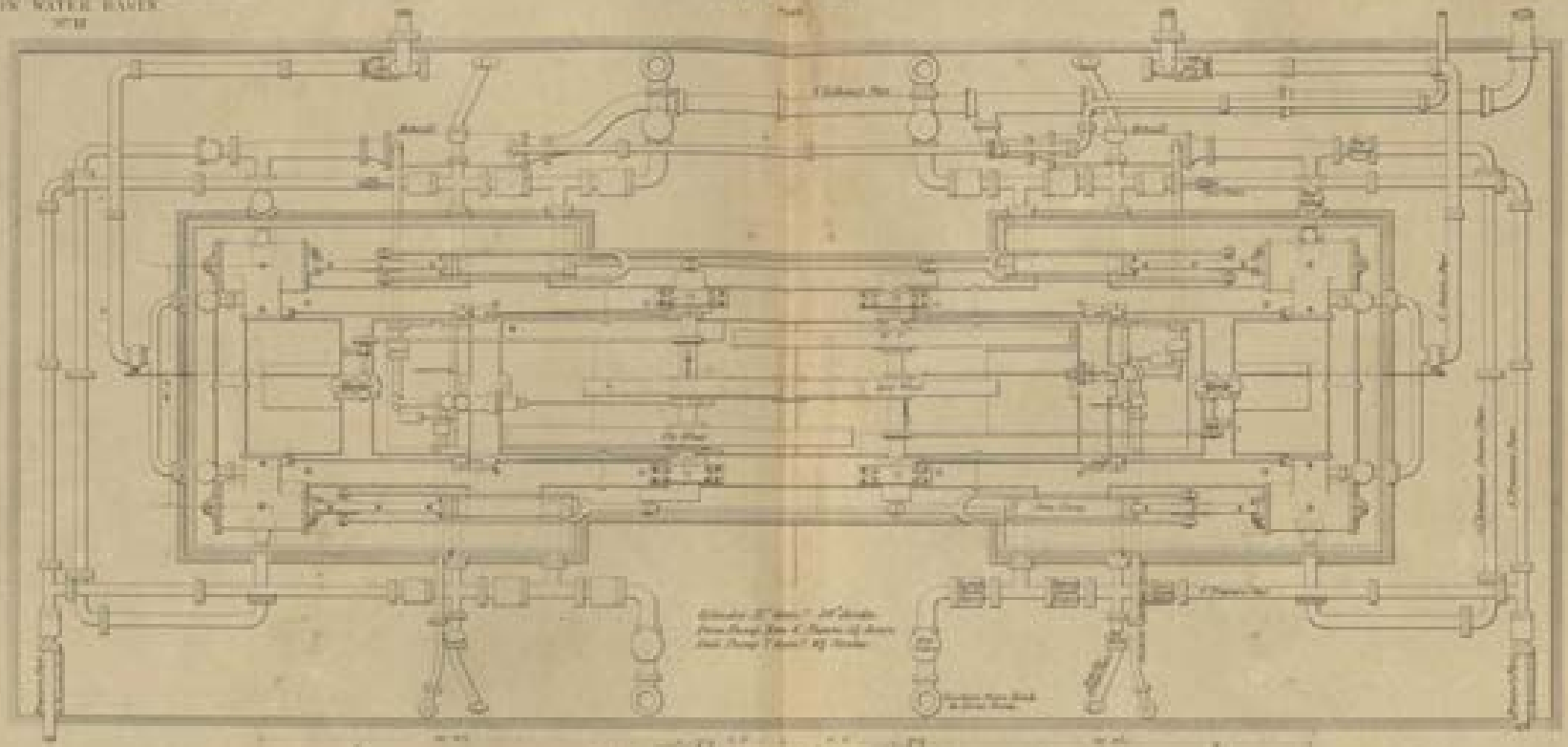


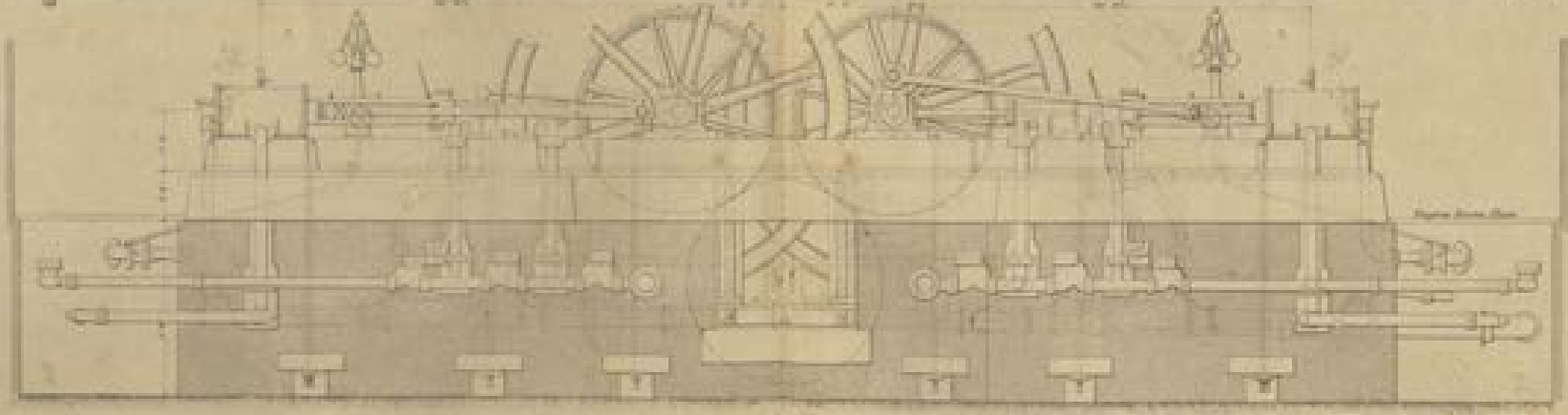




BIRKENHEAD DOCKS.

LOW WATER BASIN



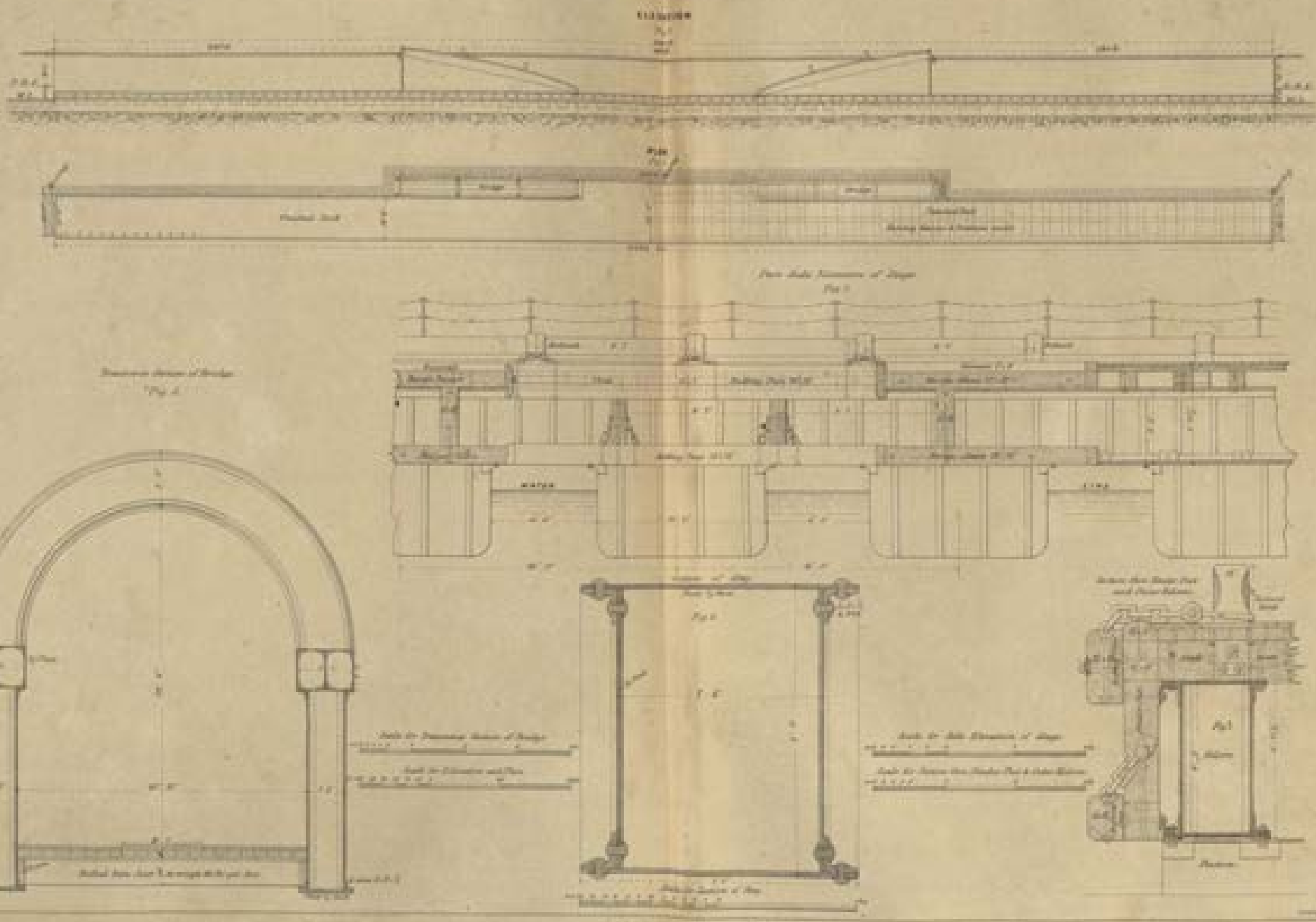


BIRKENHEAD DOCKS.

LOW WATER BASIN.

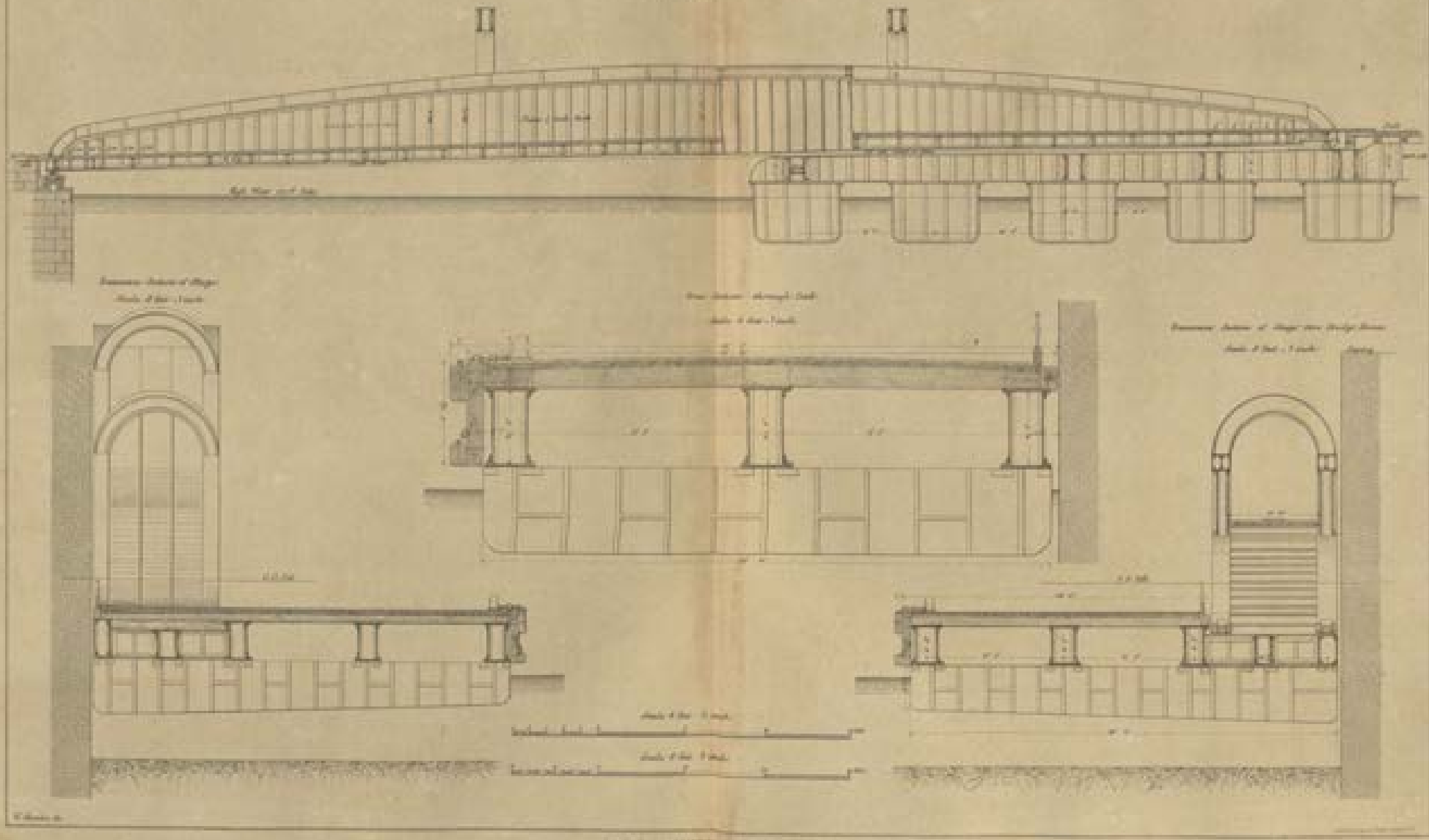
No 13.

DETAILS OF LANDING STAGE.



BIRKENHEAD DOCKS.

LOW WATER BASIN.

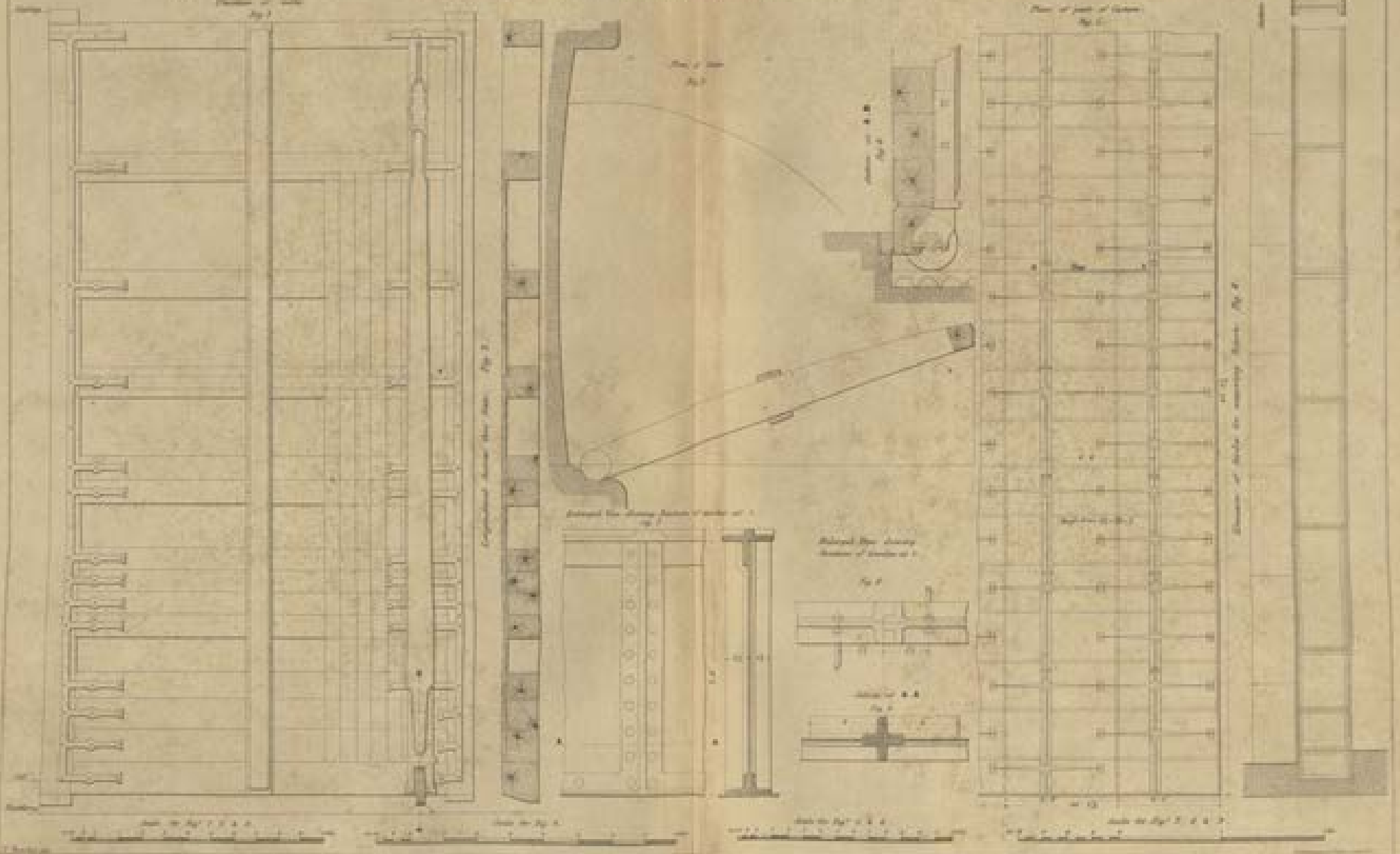


BIRKENHEAD DOCKS.

LOW WATER BASIN.

No 15.

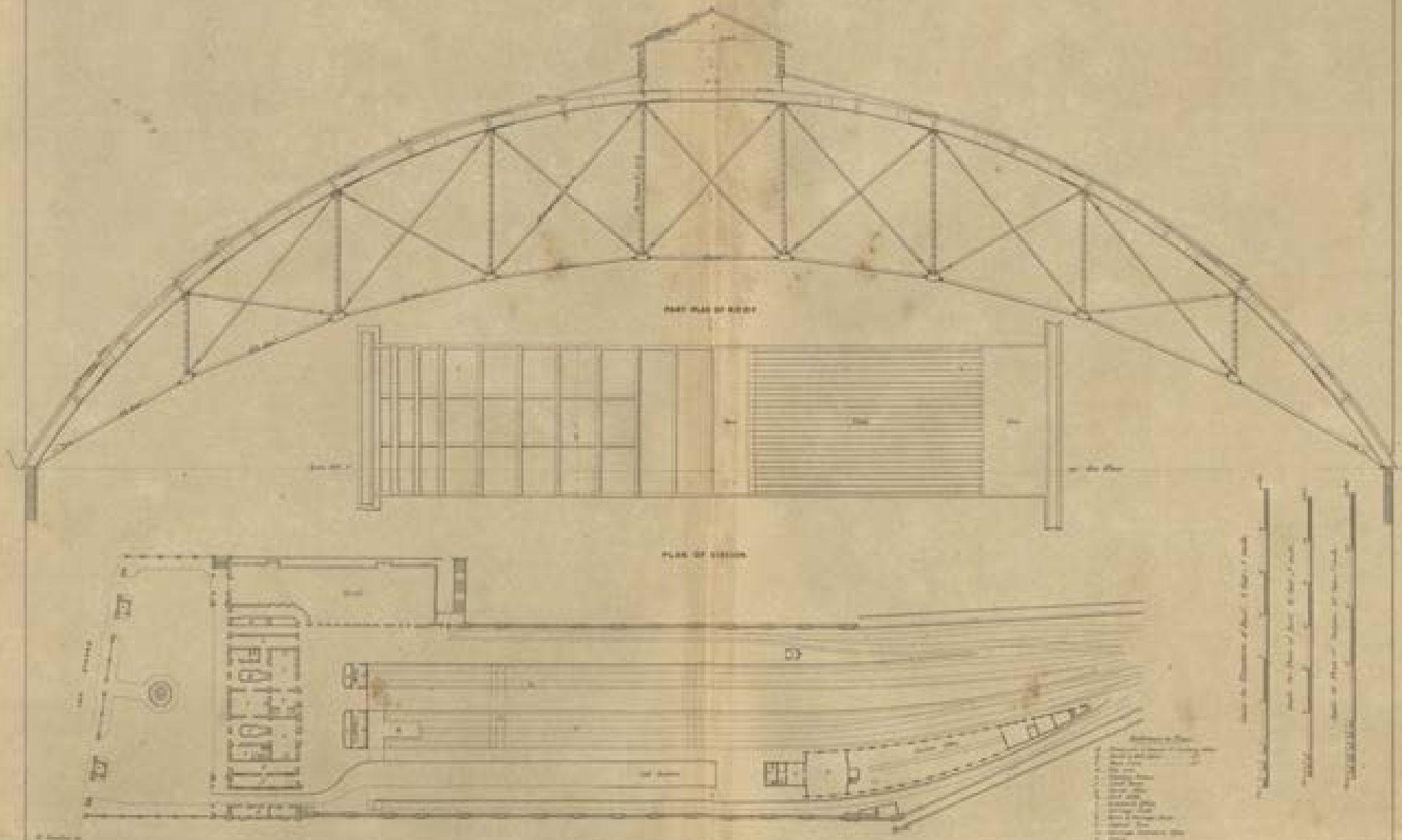
DETAILS OF LOCK GATES & MACHINERY FOR SUPPLYING HYDRAULIC ENGINE.



CHARING CROSS RAILWAY.

CHARING CROSS STATION ROOF

1864

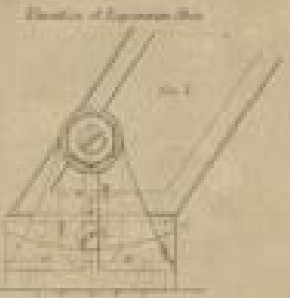


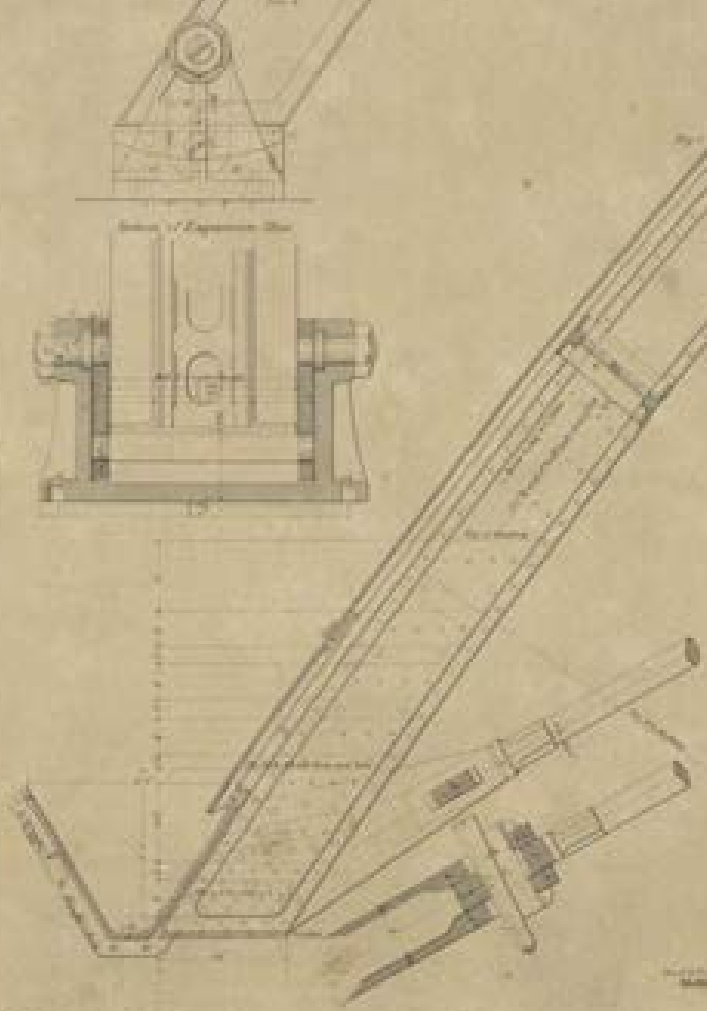
CHARING CROSS RAILWAY.

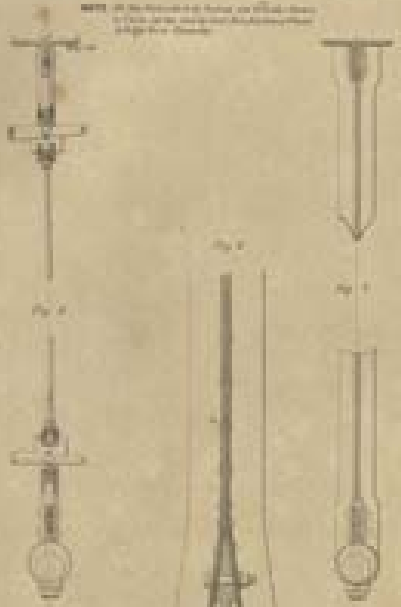
CHARING CROSS STATION ROOF

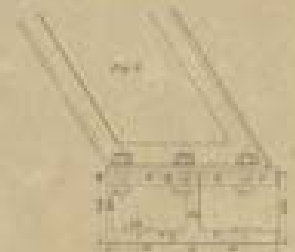
N° 2

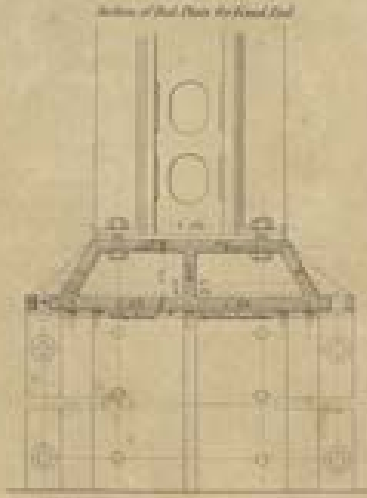
DETAILS OF ENDS OF WORKING EXPLOSIVES







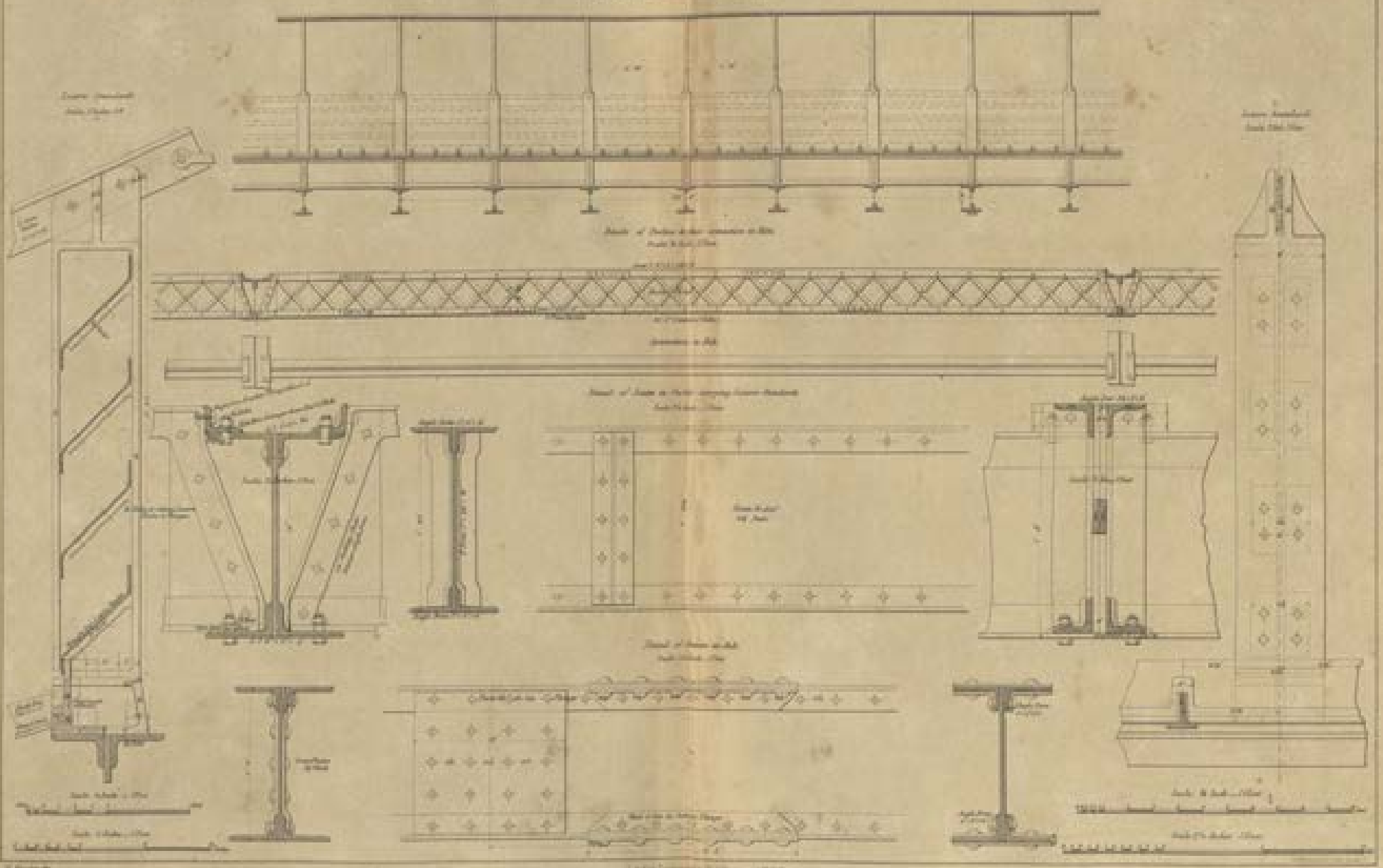




CHARING CROSS RAILWAY.

CHARING CROSS STATION ROOF.

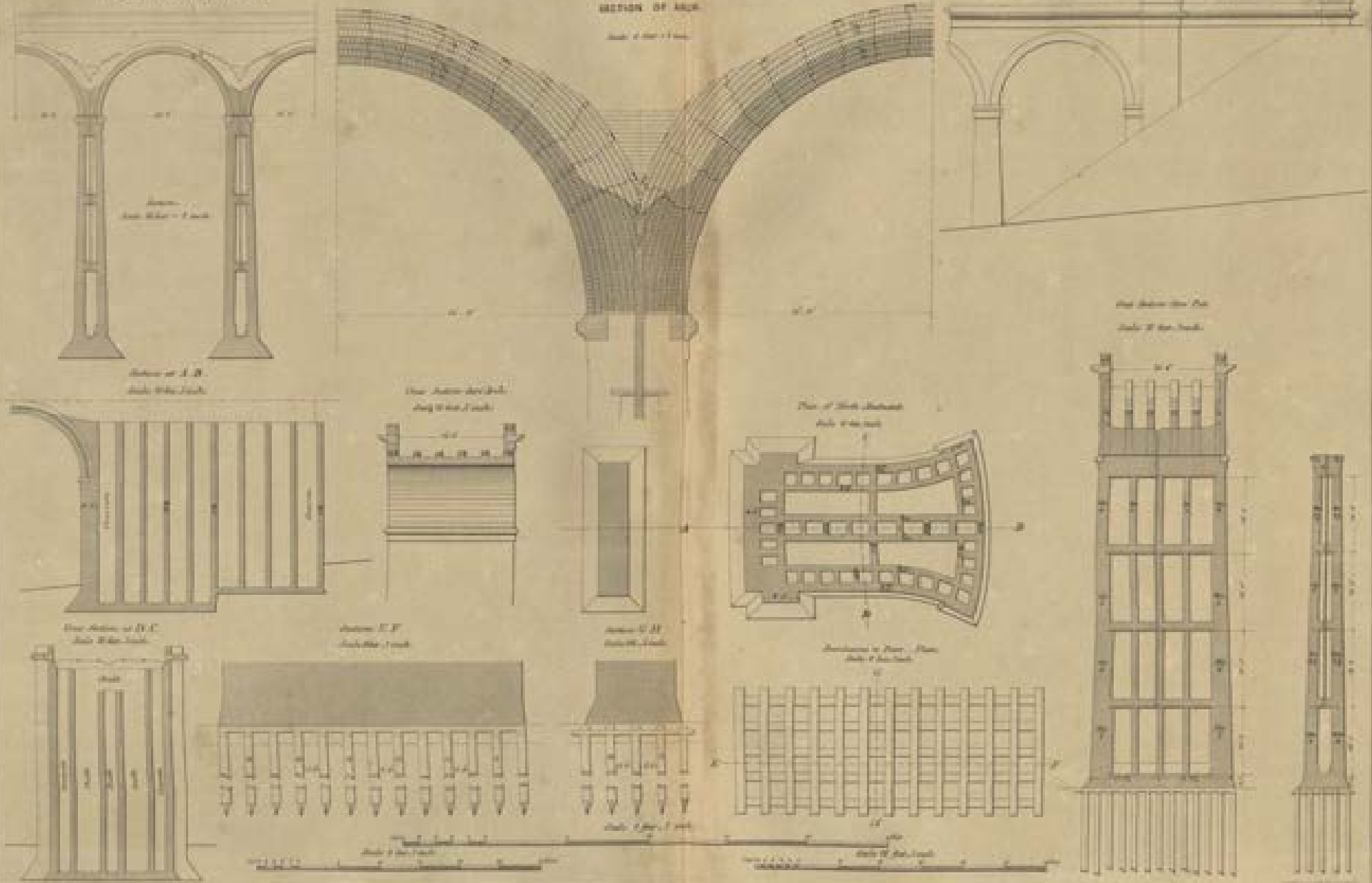
No 3.



GREAT NORTHERN RAILWAY.

HIGHWELL VIADUCT. 9 Fl.

SECTION OF ARCH.



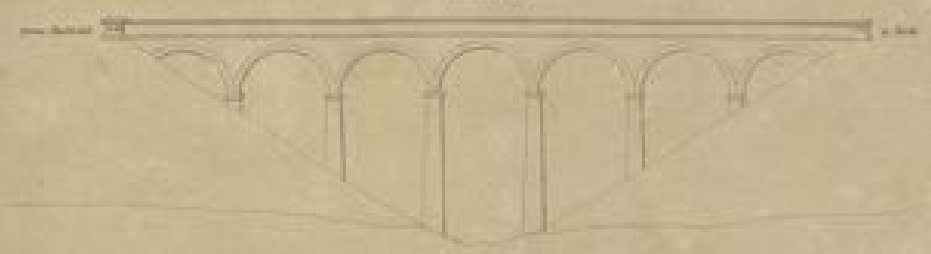
Lithographed by Day & Son

GREAT NORTHERN RAILWAY.

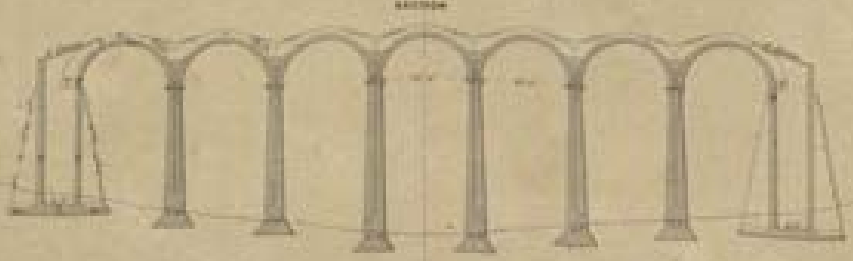
ROBBERY WOOD LANE VIADUCT

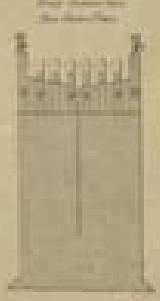
N°1

ELEVATION



SECTION

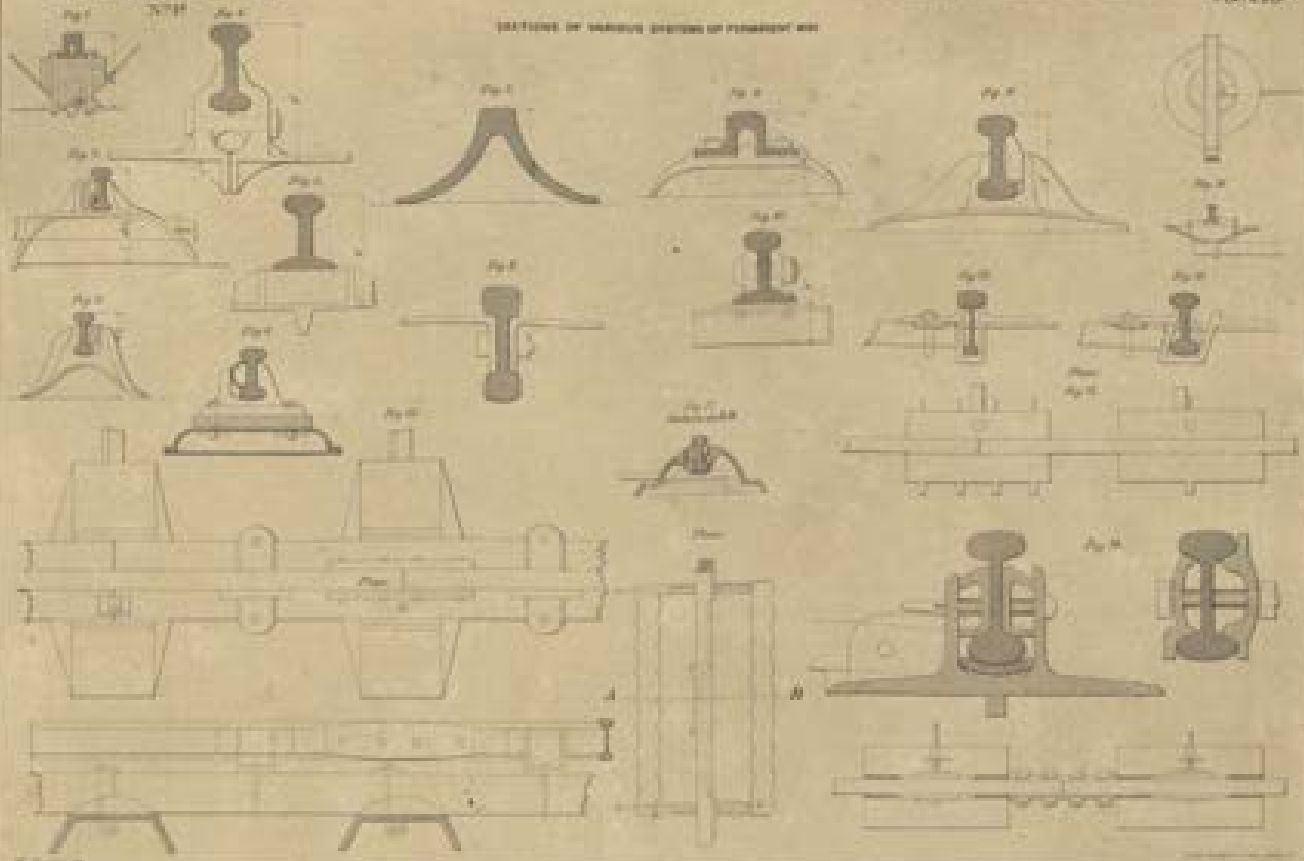




PLAN

PERMANENT WAY.

SECTIONS OF VARIOUS SYSTEMS OF PERMANENT WAY

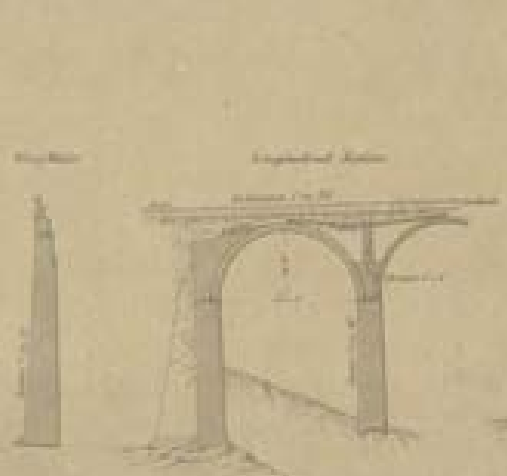


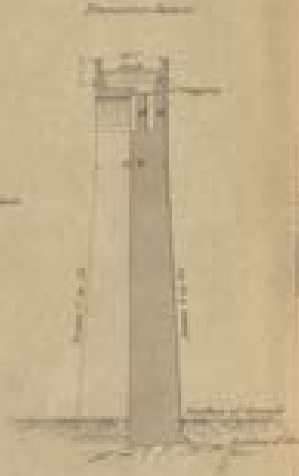
BERWYN TIDDESLAR & ABERCAYNEY RAILWAY

VIADUCT OVER CYNDACH VALLEY

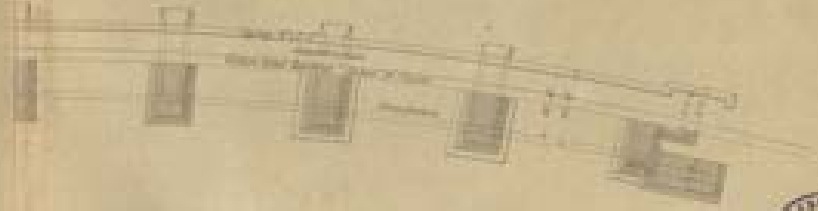
No 1

ELEVATION





PLAN

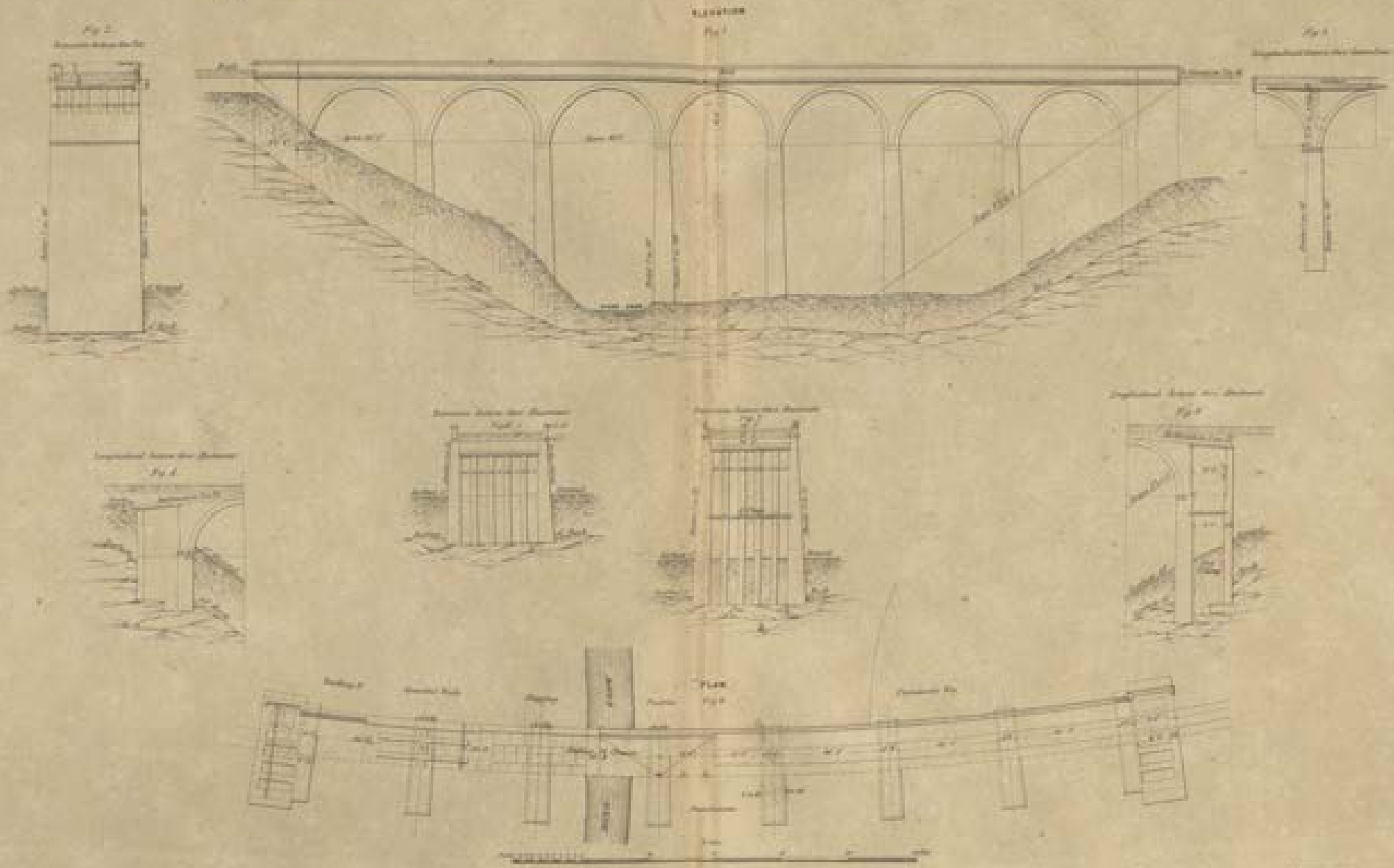


LIBRARY OF THE SURVEY BUILDING

MERTHYR TYDFILGAN & ABERGAVENNY RAILWAY.

VIADUCT OVER RIVER EBBW

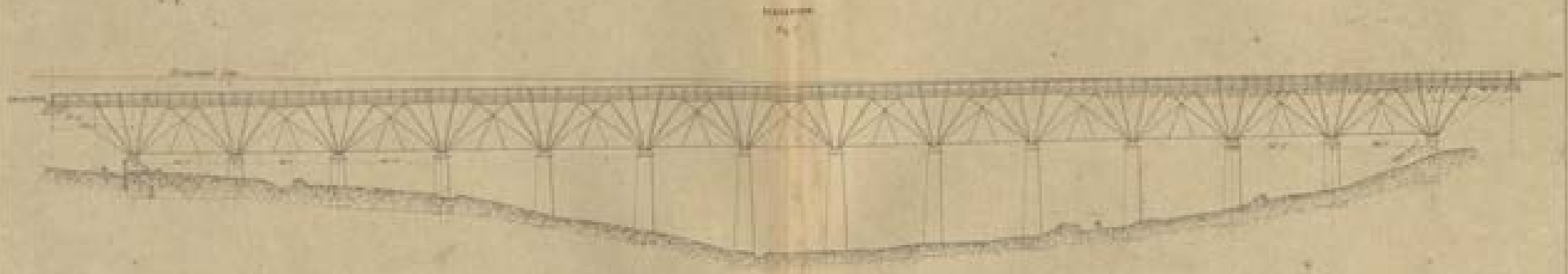
N°1.



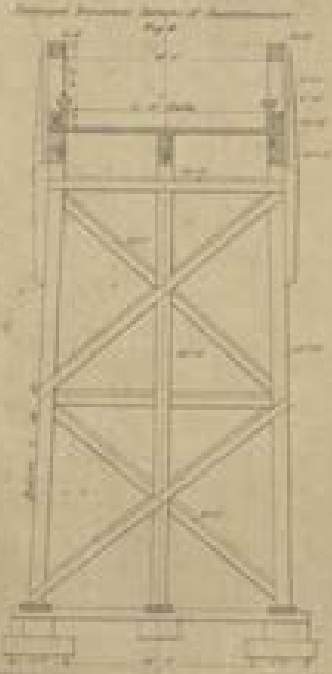
CORNWALL RAILWAY.

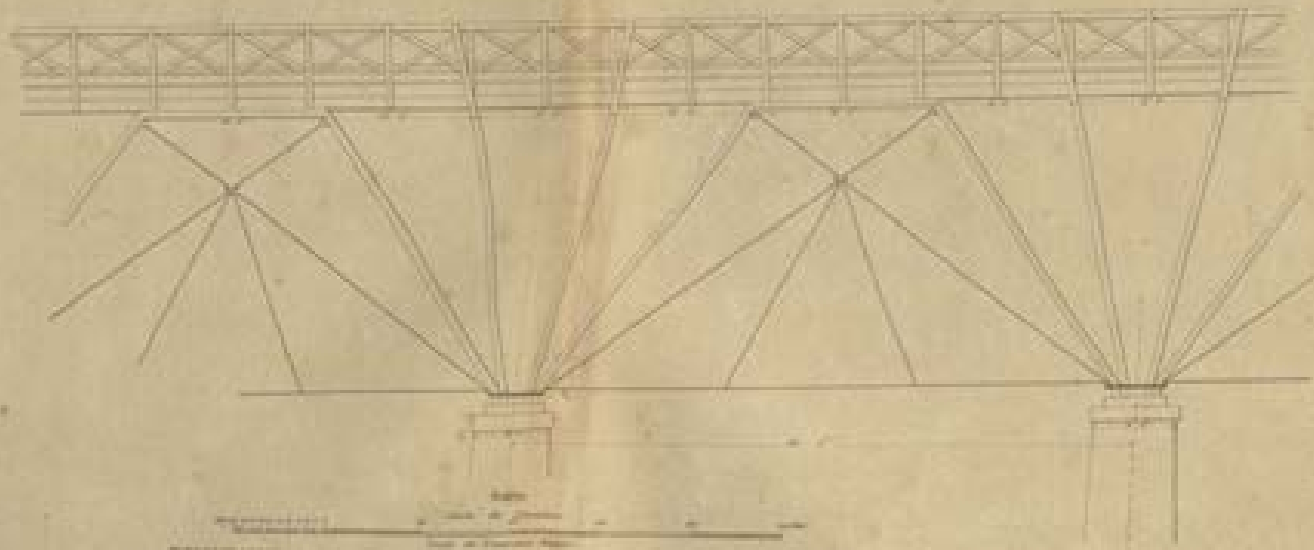
COLLEGE WOOD VIADUCT

N°1



ENLARGED ELEVATION OF SUPERSTRUCTURE.

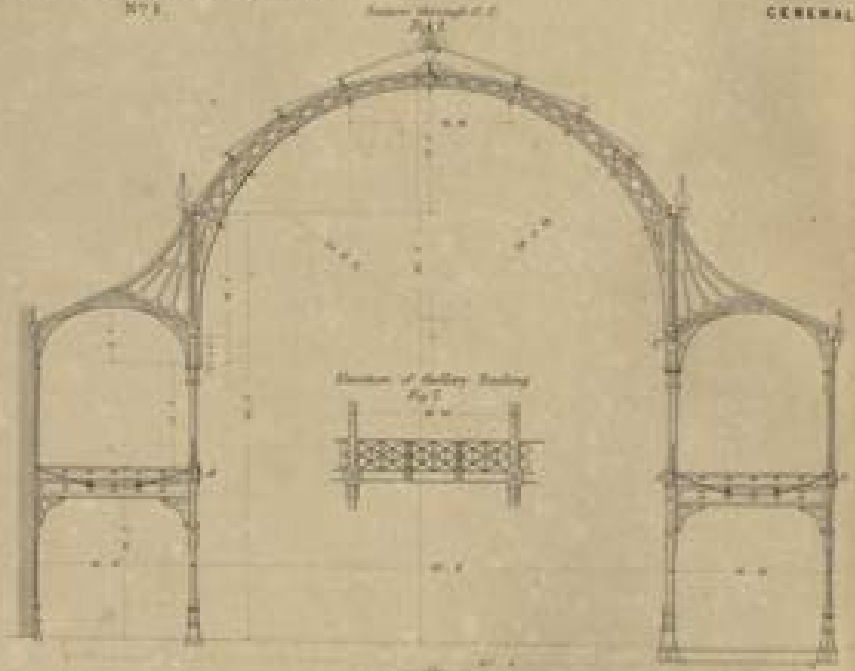


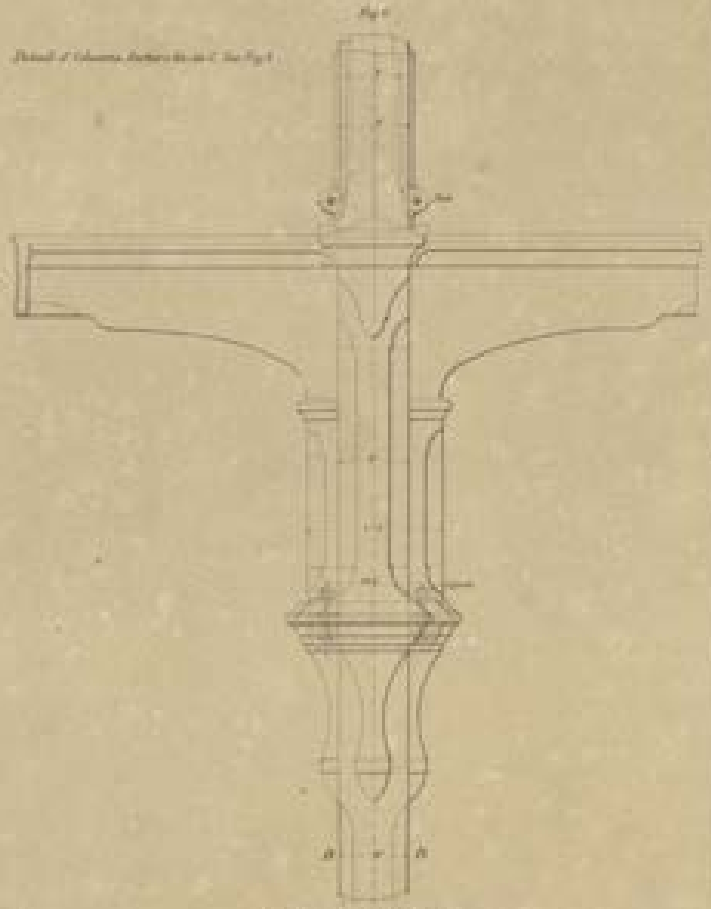


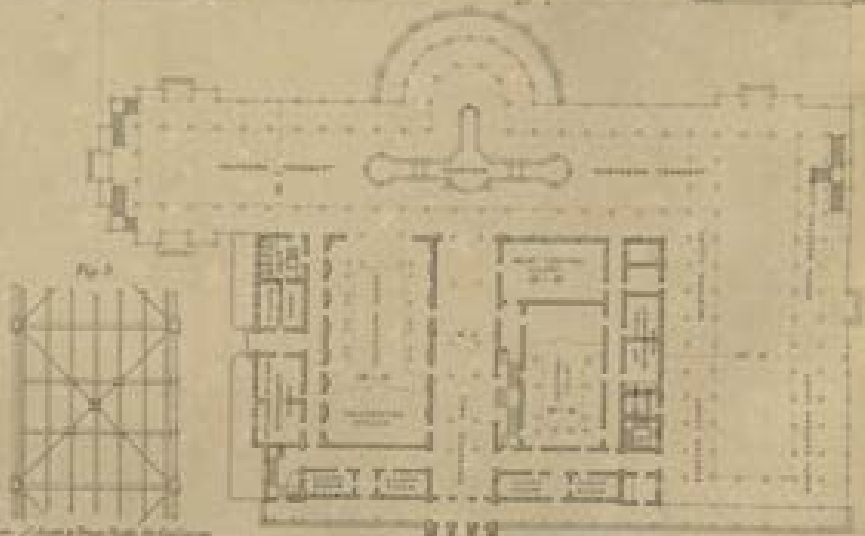
DUBLIN WINTER PALACE.

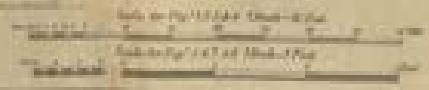
No 1

GENERAL DRAWING





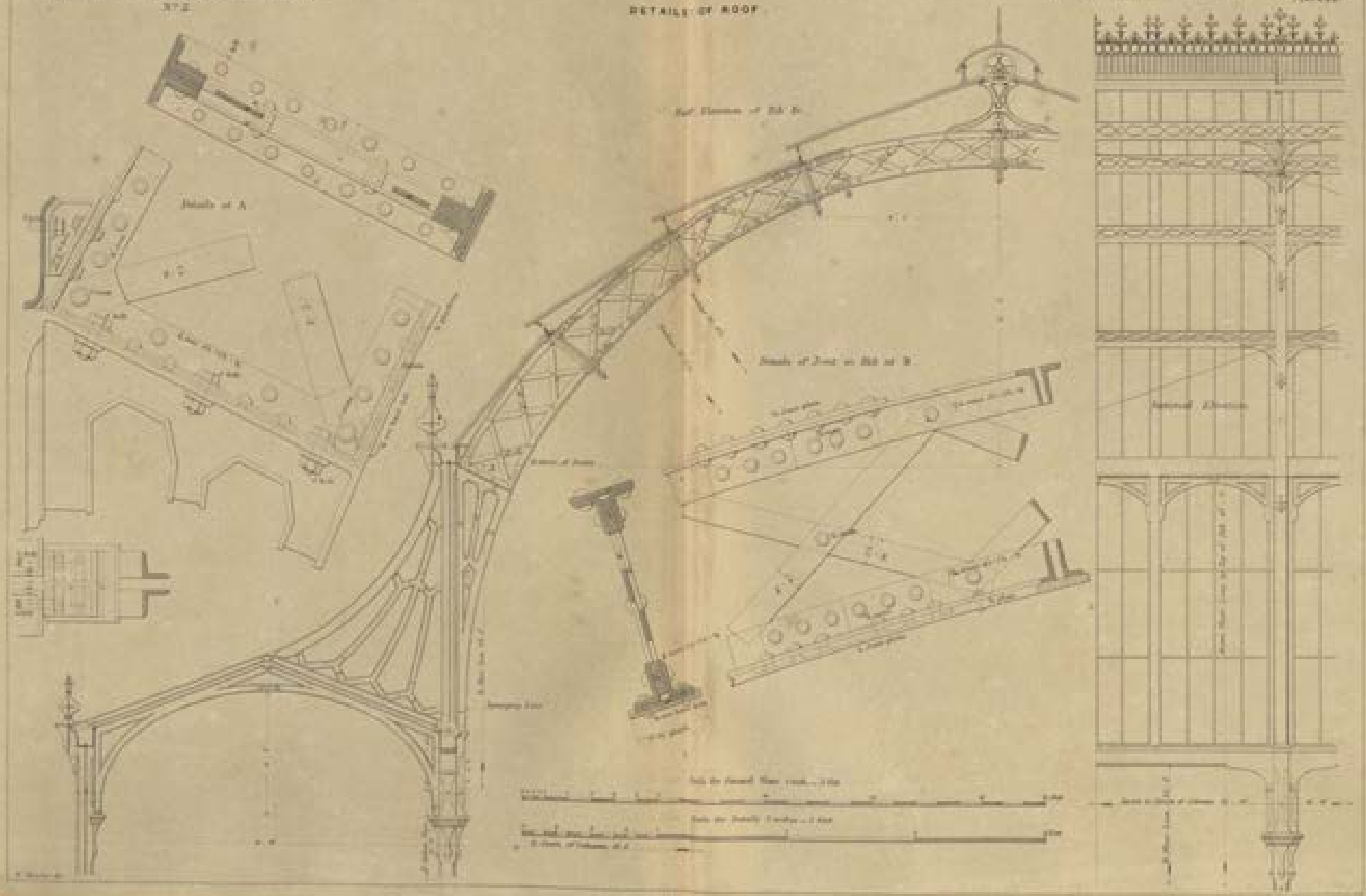




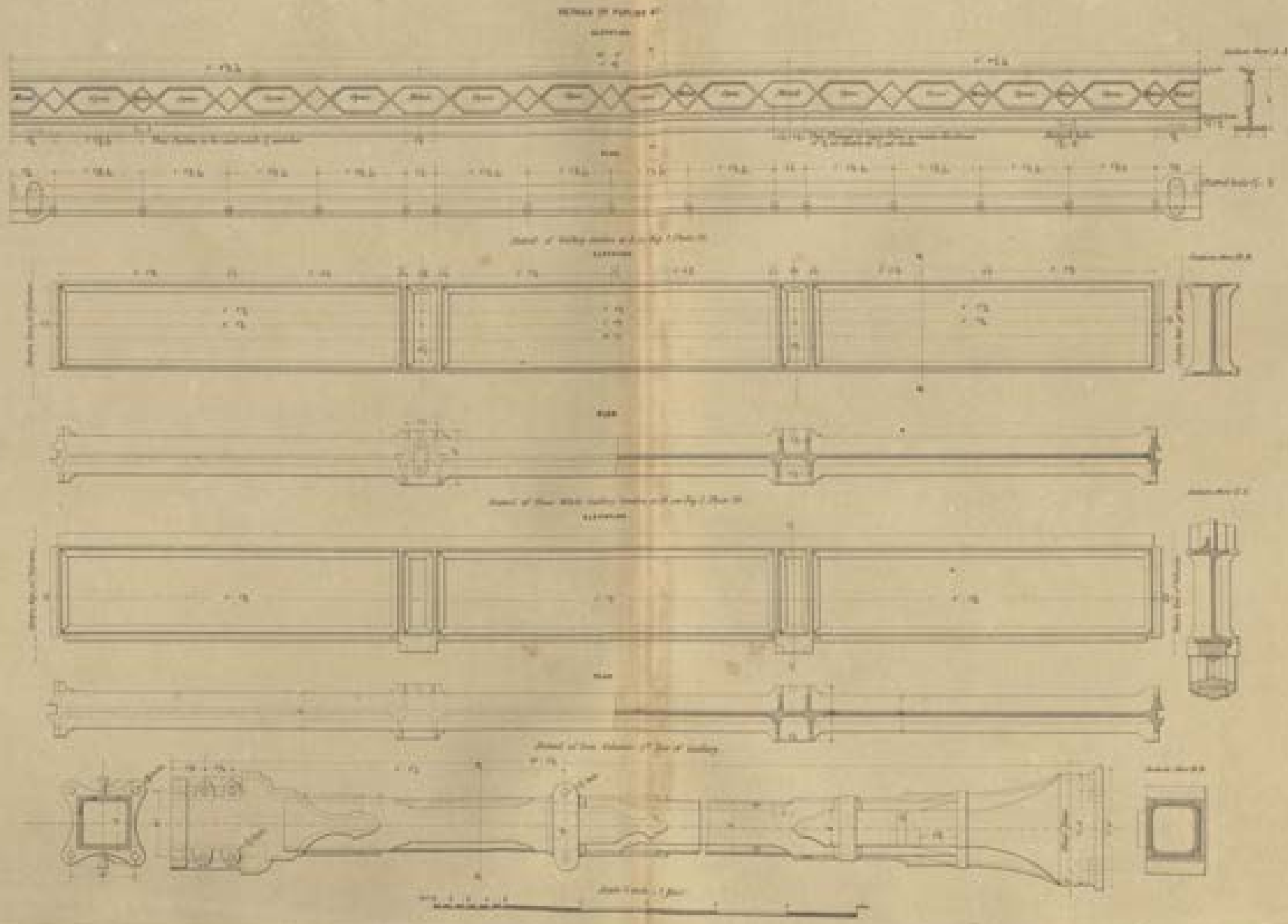
DUBLIN WINTER PALACE.

N°2.

DETAILS OF ROOF.



DUBLIN WINTER PALACE.

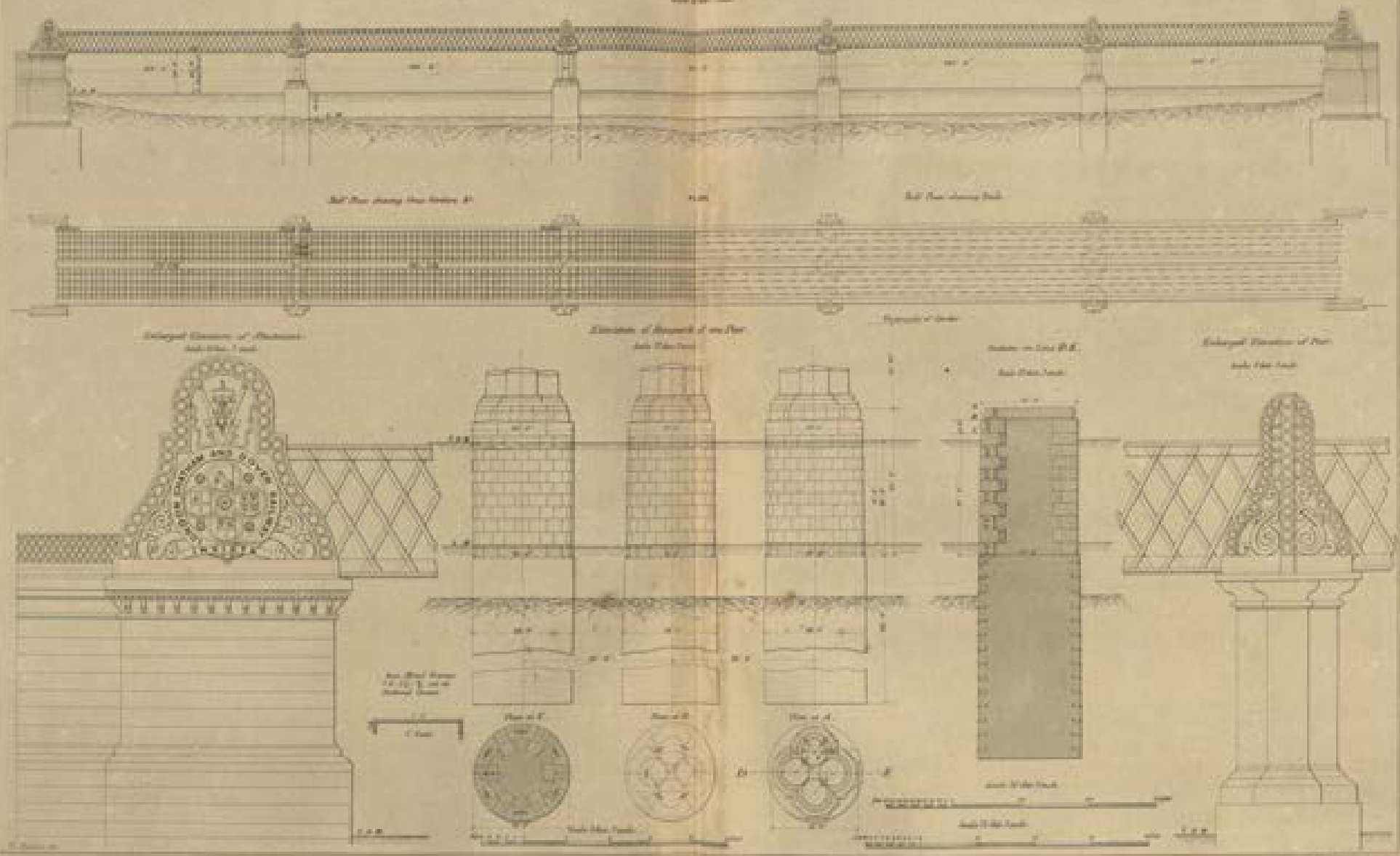


LONDON CHATHAM & DOVER RAILWAY.

BRIDGE OVER THE THAMES AT BLACKFRIARS

No 1

A SERIES OF THE PROGRESS OF MARKET ENGRAVING 1864



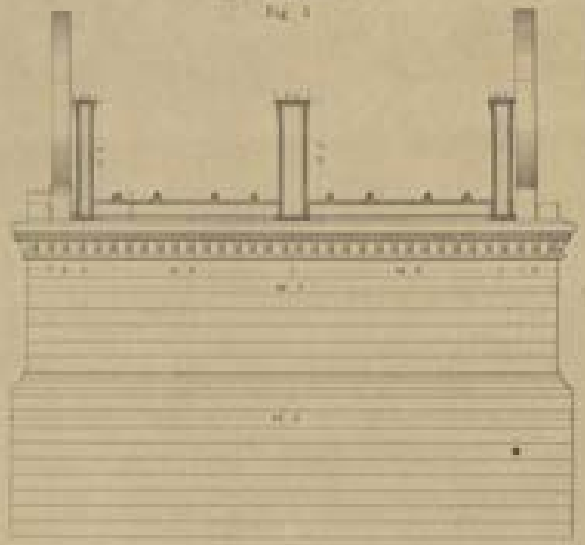
LONDON CHATHAM & DOVER RAILWAY.

BRIDGE OVER THE THAMES AT BLACKFRIARS

No 2

DETAILS OF ABUTMENTS. CROSS STAYS &c &c

Elevation of Abutment
Fig 1



Plan at Abutment
Fig 2

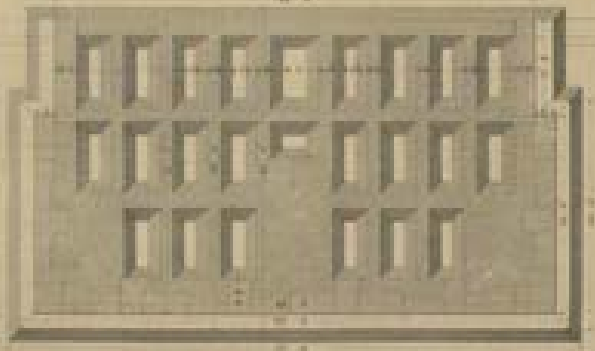
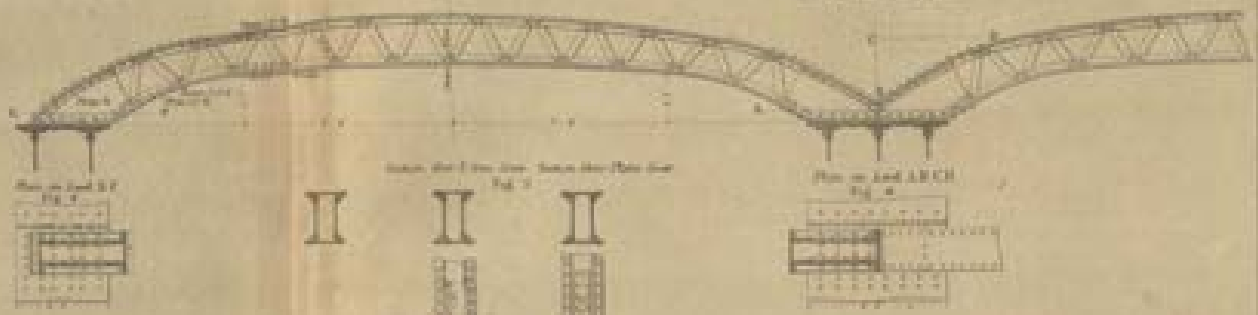


Fig 3

Elevation of River Piers
Piers in each Span

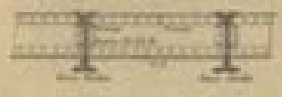


Plan on Level A-F
Fig 4

Section thro' 2 Iron Piers Section thro' Plate Girder
Fig 5

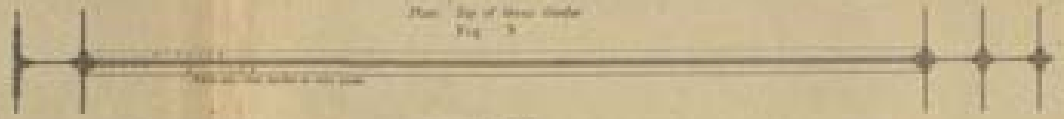
Plan on Level A B C D
Fig 6

Longitudinal Section under each Road on A B
Fig 7

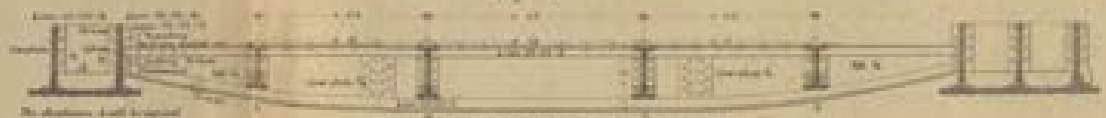


Longitudinal Section under each Road on C D
Fig 8

Plan Top of Iron Girder
Fig 9



Iron Girder
Fig 10



The Abutments & will be carried up to 75 ft on the line of Cliff to the Eastern side

Length with the 3/4 side plates and cover plates 46 feet each 20 C when one of the cover plates will be reduced by the thickness of the plates 1 where the thickness of side plates varied 3/4 the cover thickness will have to be allowed for in the length of the iron girders that appear in the centre of the girder

Fig 11

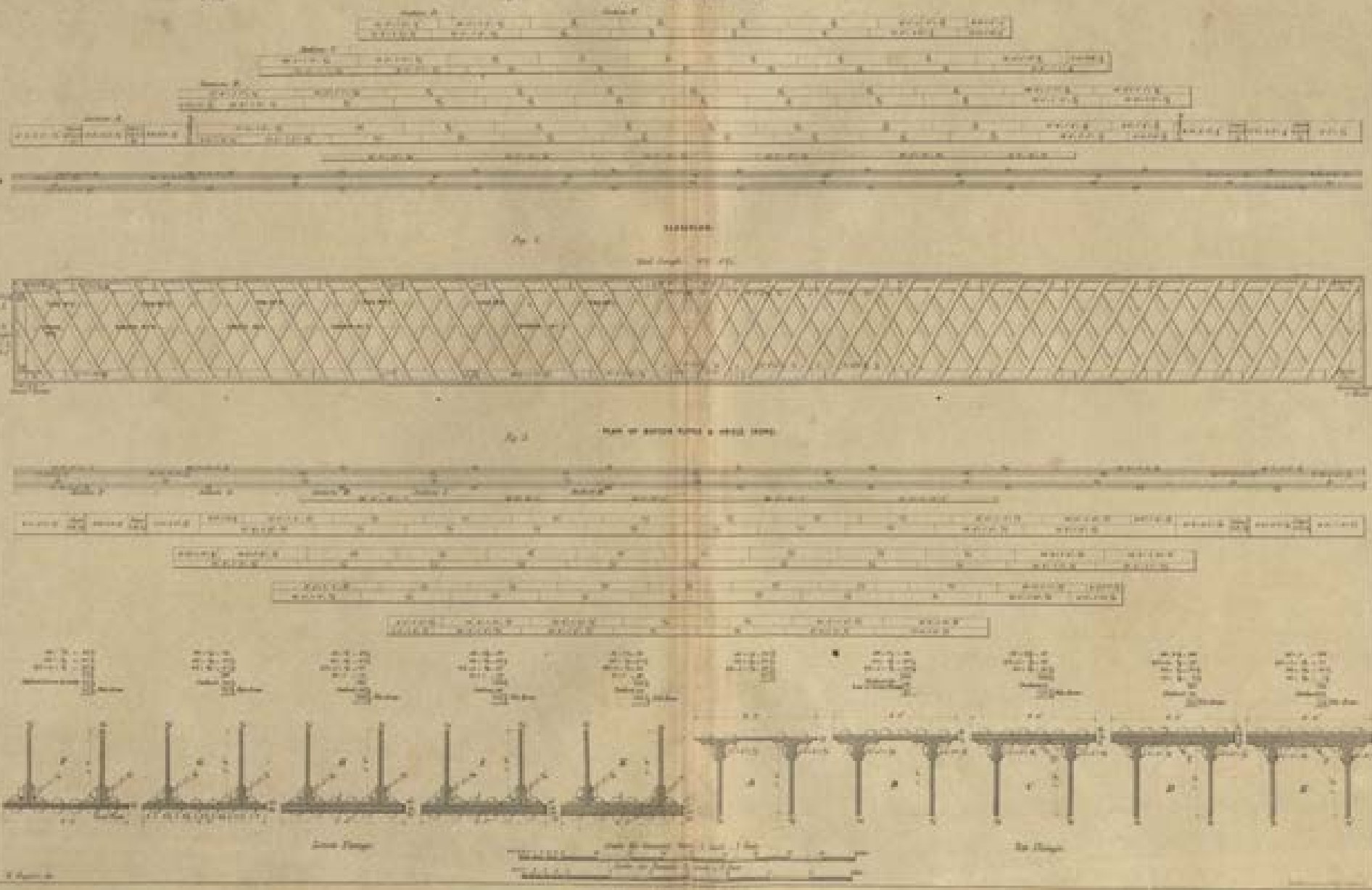
Fig 12

Scale for Details of Iron Girder

LONDON CHATHAM & DOVER RAILWAY.

BRIDGE OVER THE THAMES AT BLACKFRIARS

No 1



LONDON CHATHAM & DOVER RAILWAY.

BRIDGE OVER THE THAMES AT BLACKFRIARS.

No. 4.

A SERIES OF THE PROGRESS OF ARTISTIC ENGINEERING 1864

PLATE XIII.

GENERAL ELEVATION

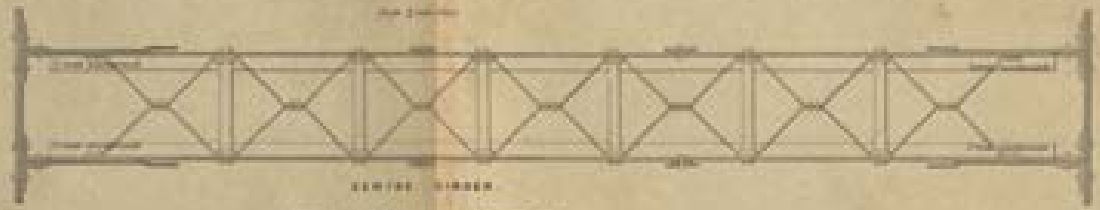
Portion of Bowstring on south shore of Lambeth and the crossing platform

Scale 8 inches 1 foot

SIDE GIRDERS.

Upper Side of a Side Girder for Four Bearing

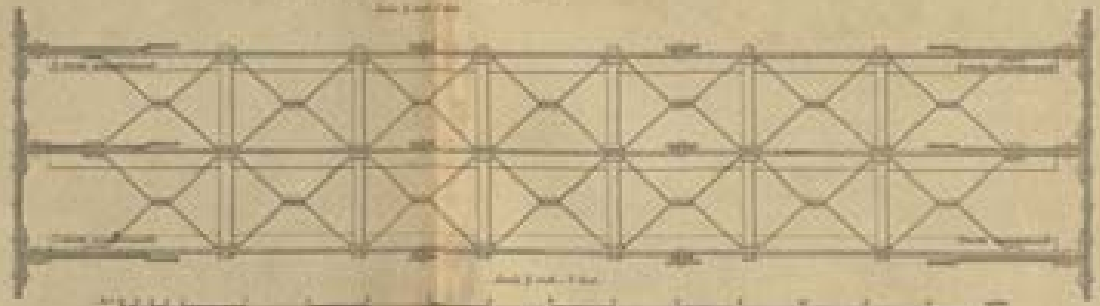
Scale 2 inches 1 foot



CENTRE GIRDER

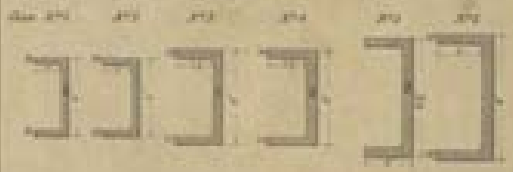
Upper Side of a Side Girder for Four Bearing

Scale 2 inches 1 foot



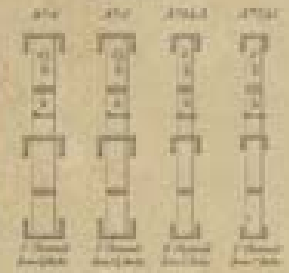
Section of Beams

Scale 3 inches 1 foot



Portion of Bearing on Longitudinal Girder

Scale 3 inches 1 foot



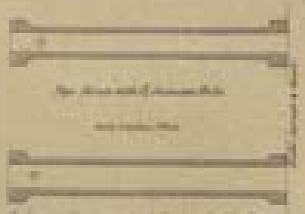
Section of Bars

Scale 3 inches 1 foot

Section on Bearing Bar

Plan Bars with Transverse Ribs

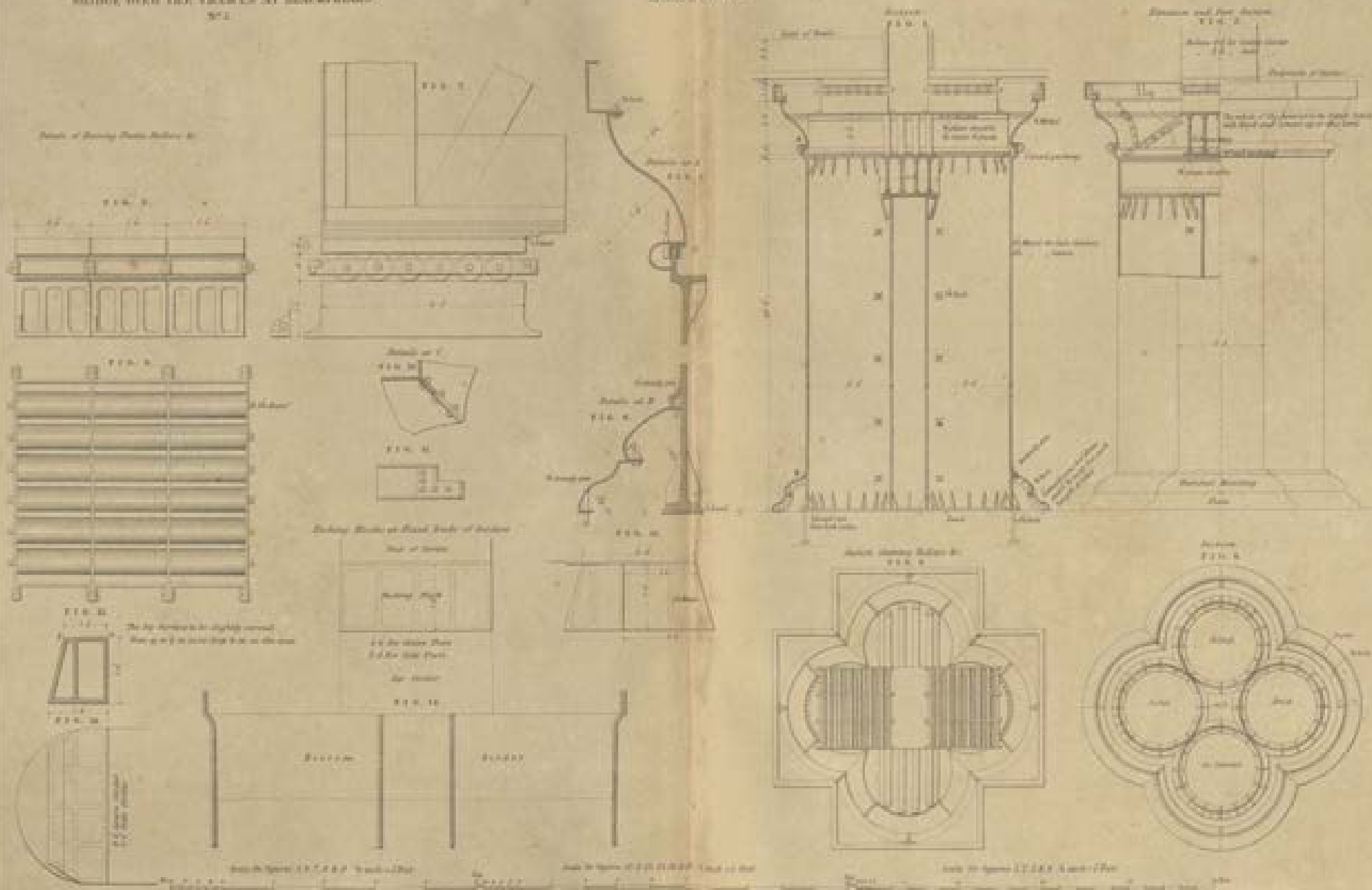
Scale 3 inches 1 foot



LONDON CHATHAM & DOVER RAILWAY.

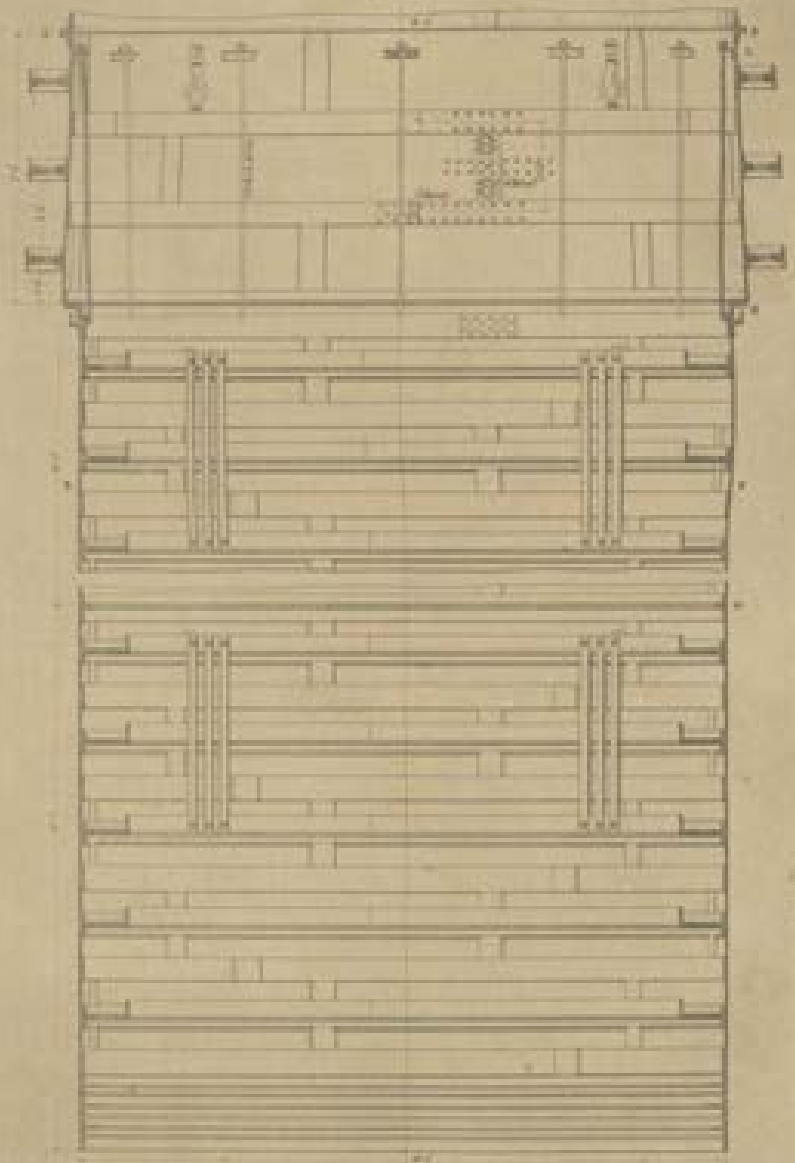
SHEDS FOR THE TRAINS AT BLACKFRIARS.

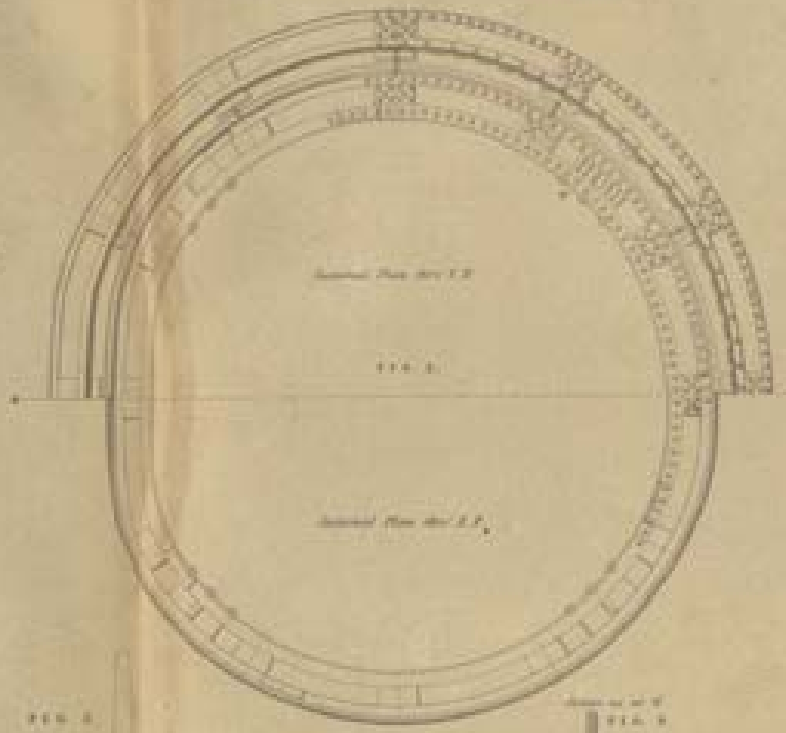
No. 1.

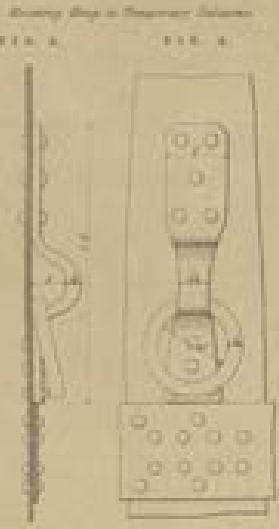


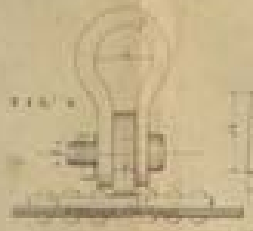
LONDON, CHATHAM & DOVER RAILWAY.

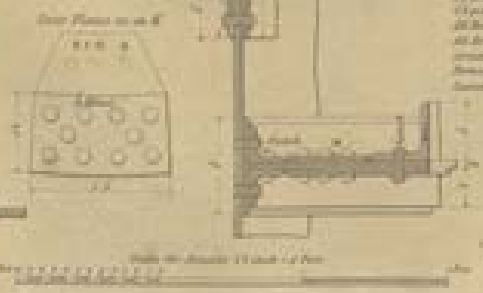
BRIDGE OVER THE THAMES AT BLACKFRIARS.





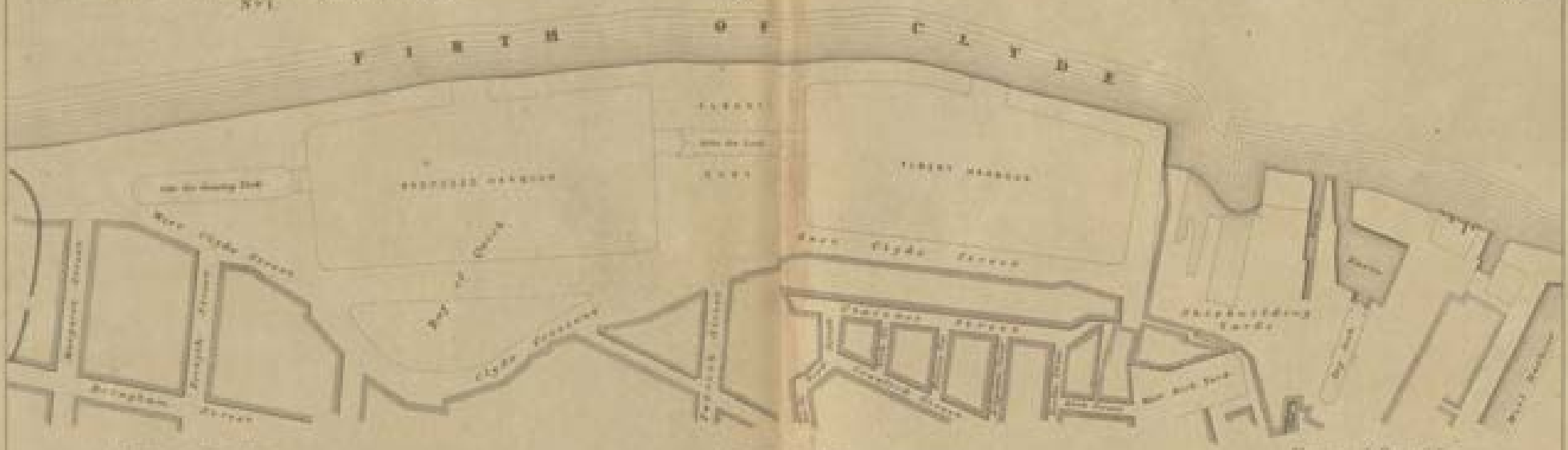




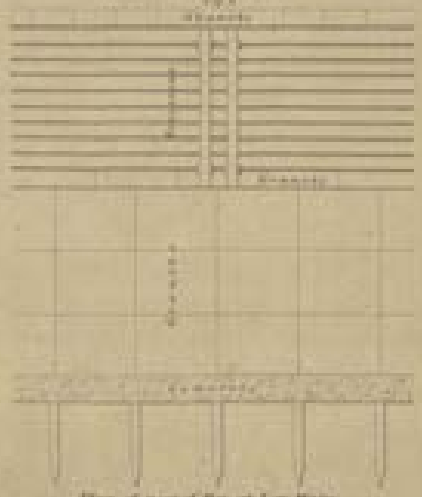


ALBERT HARBOUR GREENOCK.
No 1.

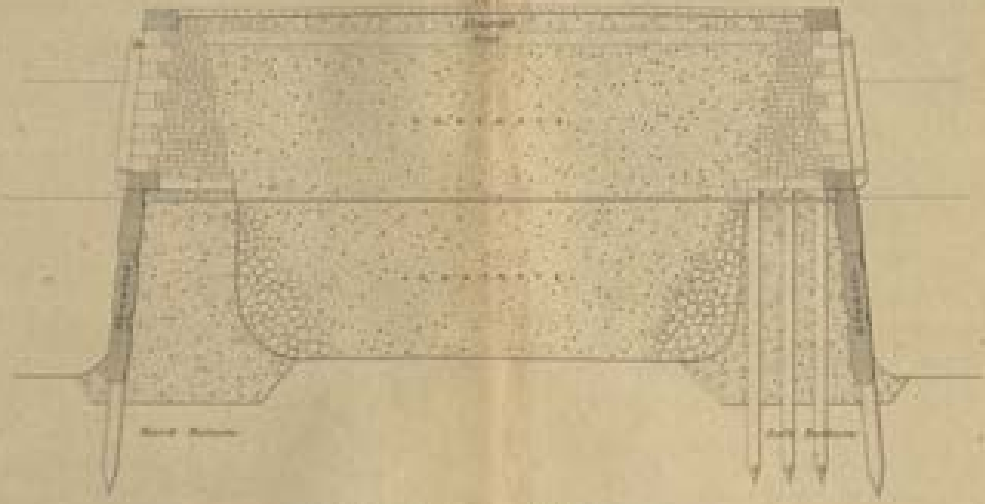
PLAN



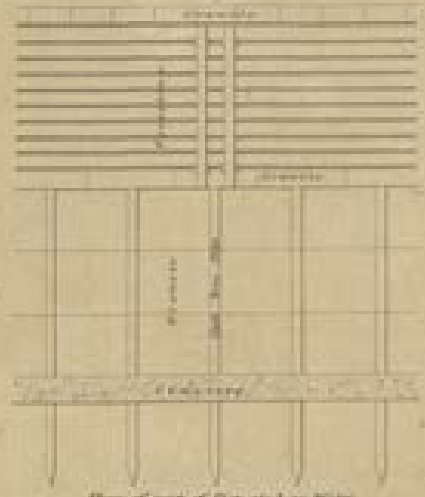
Elevation of Part of Pier
No 1



Section of Sea Pier



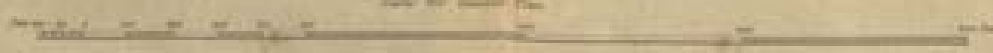
Elevation of Part of Pier
No 2



Plan of part of Pier at Low Water
No 1

Scale for Section, Elevation & Part Plans

Scale for General Plan



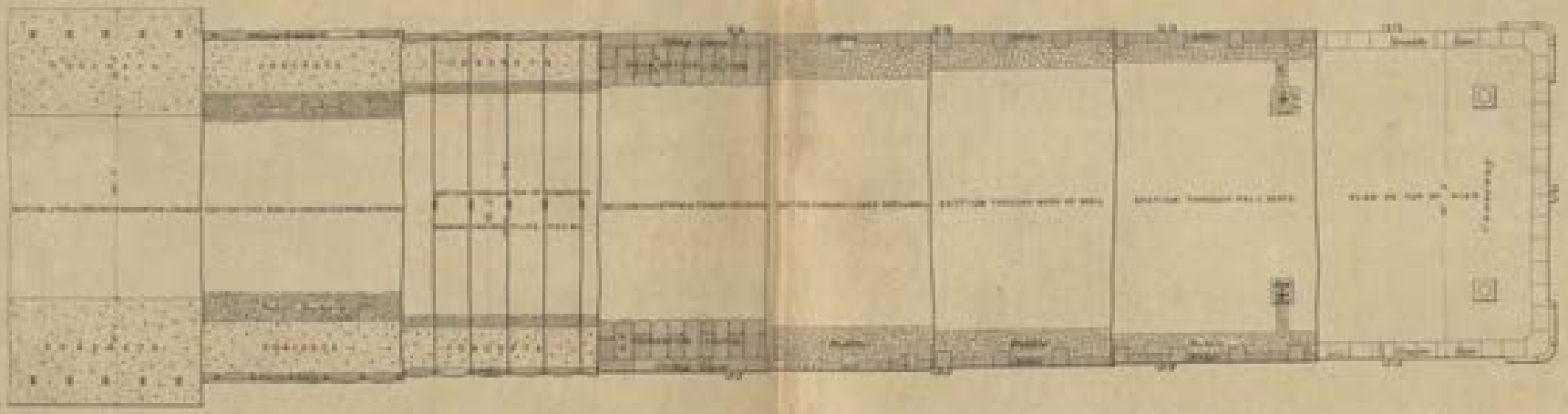
Plan of part of Pier at Low Water
No 2

ALBERT HARBOURS. GREENOCK.

No 2

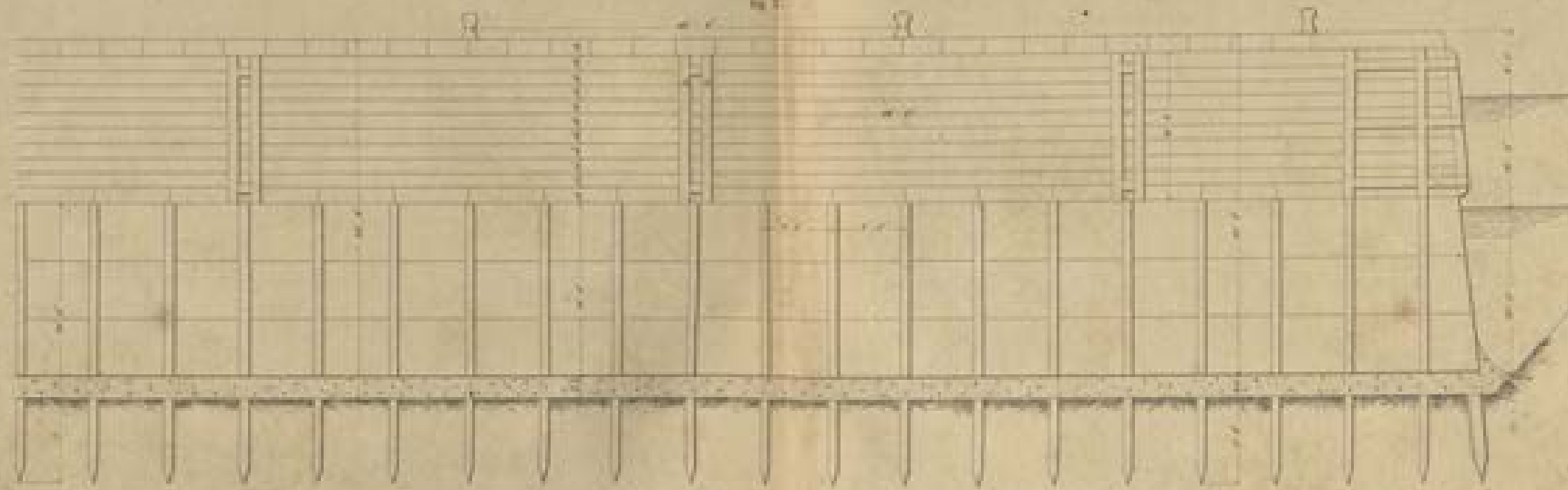
SECTIONAL PLAN SHEWING MODE OF PILING

Fig 1

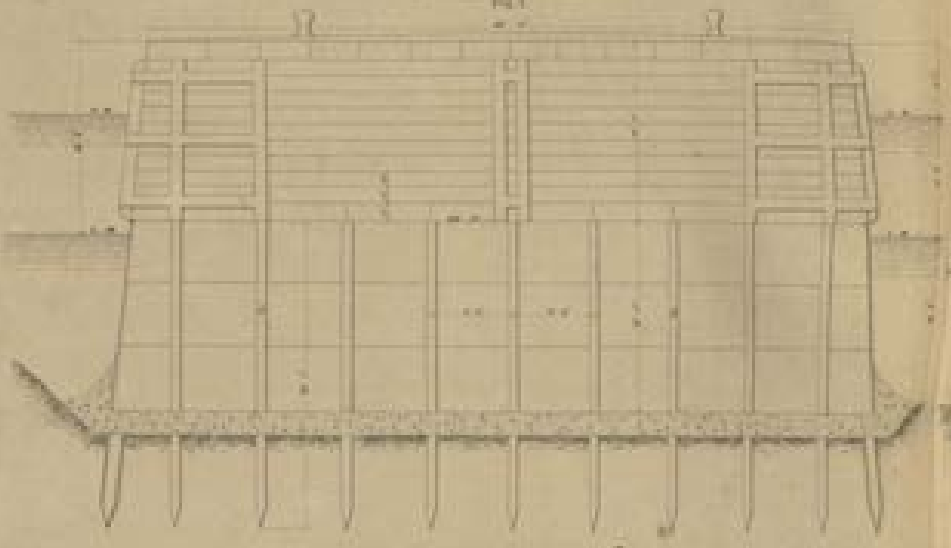


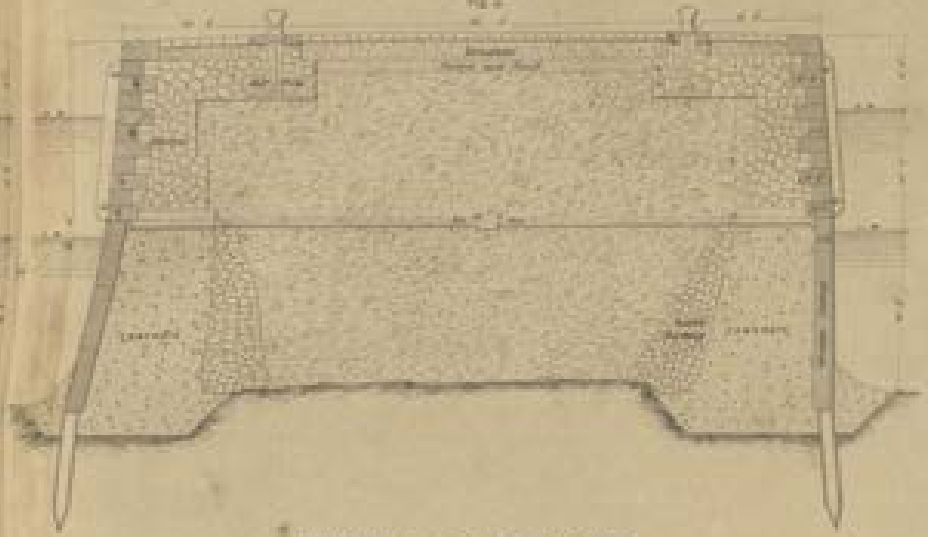
PART ELEVATION

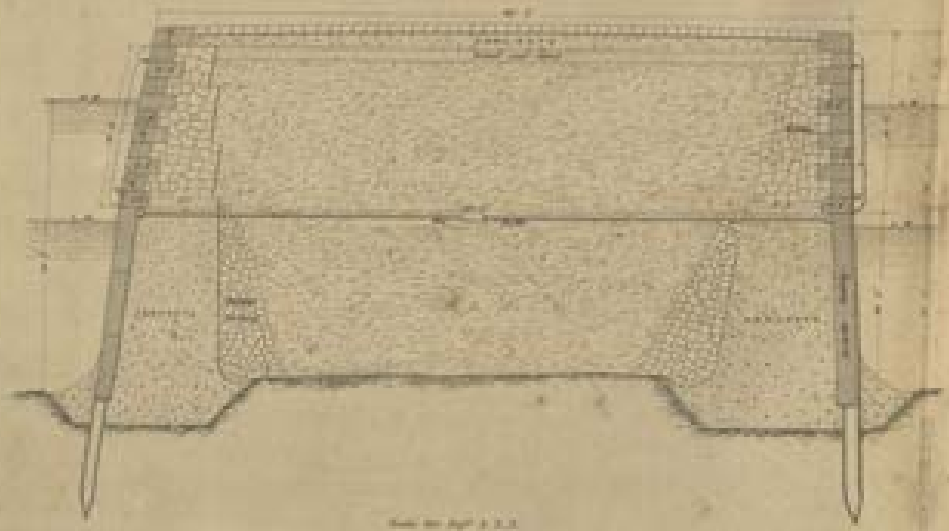
Fig 2

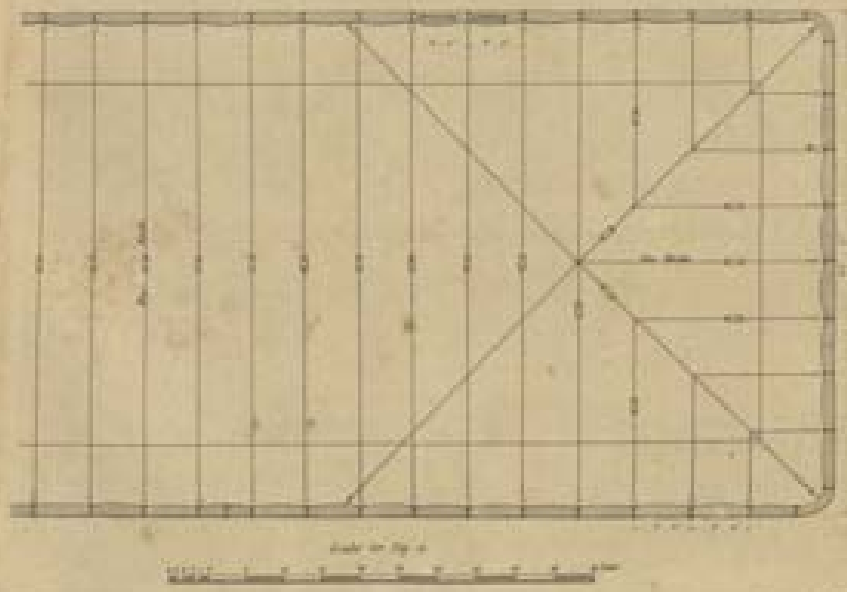


ALBERT HARBOUR'S GREENOCK.



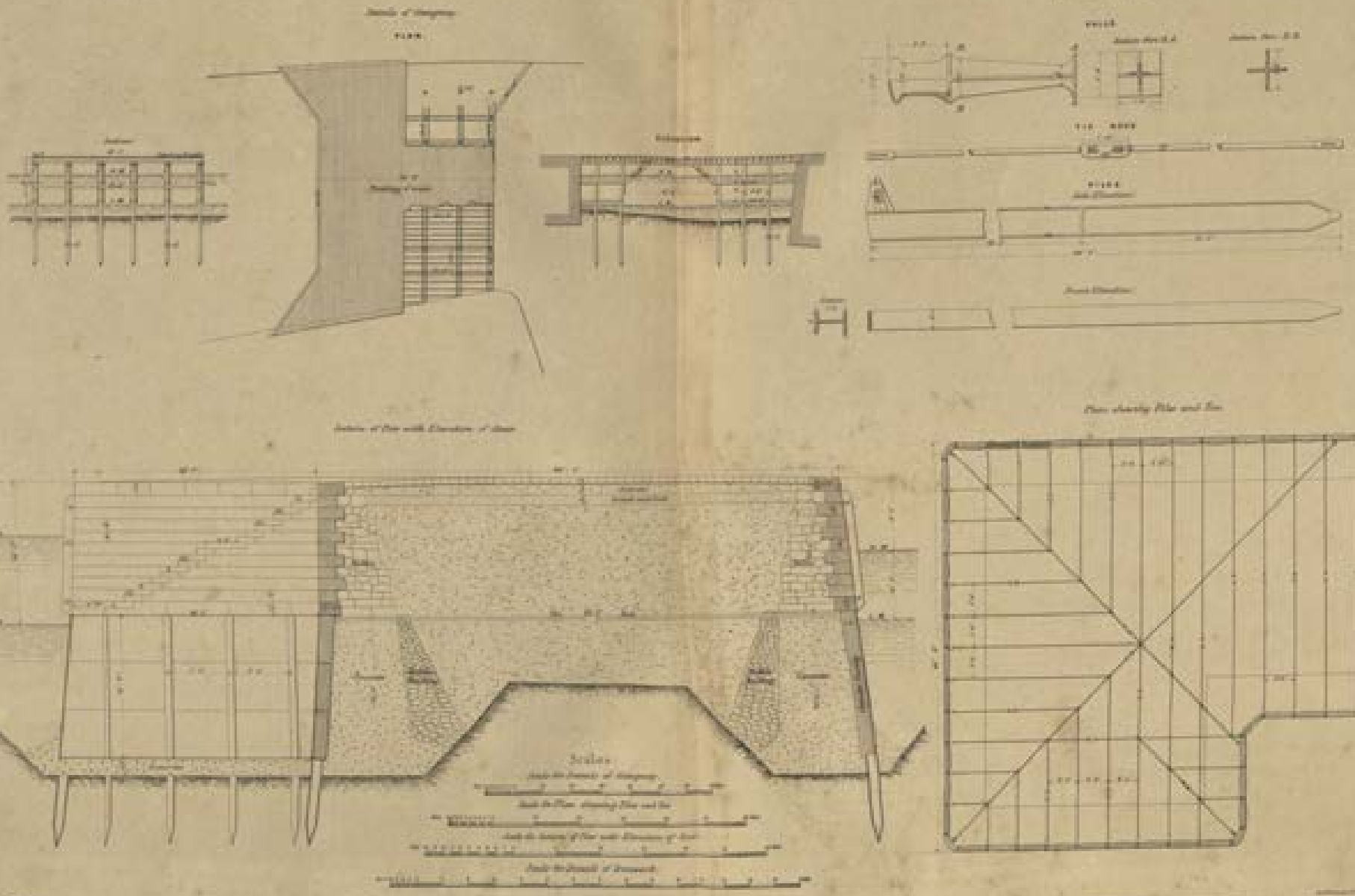






ALBERT HARBOUR: GREENOCK.

No 8.



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